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SOMMAIRE

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Directeur de la Rédaction du Bulletin : Dr Mohamed Mahmoud Alsayyad

PROF. MOSTAFA AMER
1896-1973

On March 16th, 1973, the life of a gentleman, scholar and great teacher was concluded. Prof. Amer was born on June 1896, educated in Egyptian schools and graduated in the High Technical College, Cairo. Then he winned a scholarship in Liverpool University where he obtained the M.A. Degree in Geography in 1923.

On his return, he was appointed in the High Technical College, where he had a short term until he was transferred to the newly founded Egyptian University (later Cairo University). In the Faculty of Arts, and with the help of his colleagues, Prof. Amer laid the foundations of the Department of Geography, indeed of the Egyptian school of Geography. Prof. Amer was one of the pioneers of geography in Egypt, not only in the University, but in schools as well. Many of us still remember his series of geographies for secondary schools. He wrote then as he used to lecture in lucid well ordered and disciplined manner. For many years his «Principles of General Geography» in which he collaborated, remained a source of inspiration and insight in the discipline of geography,.

With the collaboration of the Late Prof. Oswald Menghin he started the excavations of Maadi pre-historic site in 1930 and continued his work there until the end of his life. With his usual elegant, careful and cautious way he could bring to light a whole neolithic village.

Prof. Amer occupied many educational posts. He has been Dean of the Faculty of Arts (1948), Vice rector of Cairo University (1948/50), Rector of the University of Alexandria (1952) and Director of the Department of Antiquities (1954). When he retired he was called by Saudi Arabia to be the Honorary Chancellor of the newly founded University at Riadh.

Prof. Amer has been in fact intellectually active until the very last day of his life. He has been the first Egyptian scholar to be Director of the Council of the Egyptian Geographical Society.

For his many students Prof. Amer will be the symbol of elegance, wit and far-sightedness.

M.S. Ghallab

THE MORPHOLOGY OF THE LOWER SECTION OF WADI HILAL

A TRIBUTARY DRY VALLEY OF THE NILE, SOUTH OF ESNA, UPPER EGYPT

BY

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INTRODUCTION

This article is an attempt at the interpretation of selected morphological features of the lower section of WADI HILAL, whose twin confluence with the NILE lies about 18 km. to the south of SIBAIYA in UPPER EGYPT. On two occasions of c. 10 days each (in October 1969 and 1970), the writer had the opportunity to carry out field investigations which revealed the following striking features :

1. A well-developed «Valley-in-valley» form which may be attributed to fall in the base-level, or may be a reflection of changes in the climatic conditions during the recent geological periods (Pleistocene and Recent), or may be a result of both reasons.

2. The close relationship between the geology and the various types of mass-wasting has been clearly demonstrated. It is interesting to point out that this relationship coincides clearly with the convex bend of the dry channel meander.

3. At a point, in the midway between the two confluences of Wadi Hilal with Khor Yassen and Khor Abou Malahia, Wadi-Hilal splits into two well-developed valleys, the southern of which joins the Nile at Naga-Hilal while the northern joins the Nile at Naga El-Mahamid. The two valleys embrace a high ground, the level of which rises to about 180 m.

above sea-level and about 100 m. above the valley-floors. (Contour Map F. 1).

It is necessary, however, before discussing these major geomorphological features, to give a brief account of the general topographic and geologic characteristics of the area under consideration.

GENERAL TOPOGRAPHY AND GEOLOGY

Topography :

The area investigated here (Fig. 1) is a very small part of the basin of Wadi Hilal which occupies a much bigger area of the Eastern Plateau of Egypt. The lower section of Wadi Hilal which extends inland from its confluence with the Nile for about 20 kilometers, is bounded by a water-shed separating it from Wadi Oweinya in the north and Khor Mafalis in the south. The main valley of Wadi Hilal receives numerous tributary valleys, the most important of which, particularly in the lower section are Khor Yassen with its tributary Khor Awad on the eastern side, and Khor Abou Malahia on the Western side.

The area of Wadi Hilal and the adjacent areas is geologically known by «Eastern Mahamid», which represents high uplifted plateau intensively dissected by deep valleys (Wadis). The plateau tilts from the south-east to the north-west according to the general dipping of the rock beds. The prevailing elevations measuring 145-150 meters above sea-level are typical of the Sharawna locality, while the isolated flat uplands with elevations reaching 240-300 meters above sea-level composed of the younger Eocene formations appear at the north-eastern outskirts of the area under consideration. At the Oweinya locality, the plateau is 160-200 meters above sea-level and some peaks located at its north-eastern part reach 240-270 meters. The south Qurayat and Hagaria localities form flat cuesta surfaces with elevation measuring 210-230 m.

Within the limited area of the lower section of Wadi Hilal shown on Fig. 1, the elevation of the summit areas varies from about 310 in the extreme north to about 240 in the extreme south. The valley floor descends from 200 meters to about 90 meters which is the limit of the present day flood plain of the Nile. Although this area is everywhere

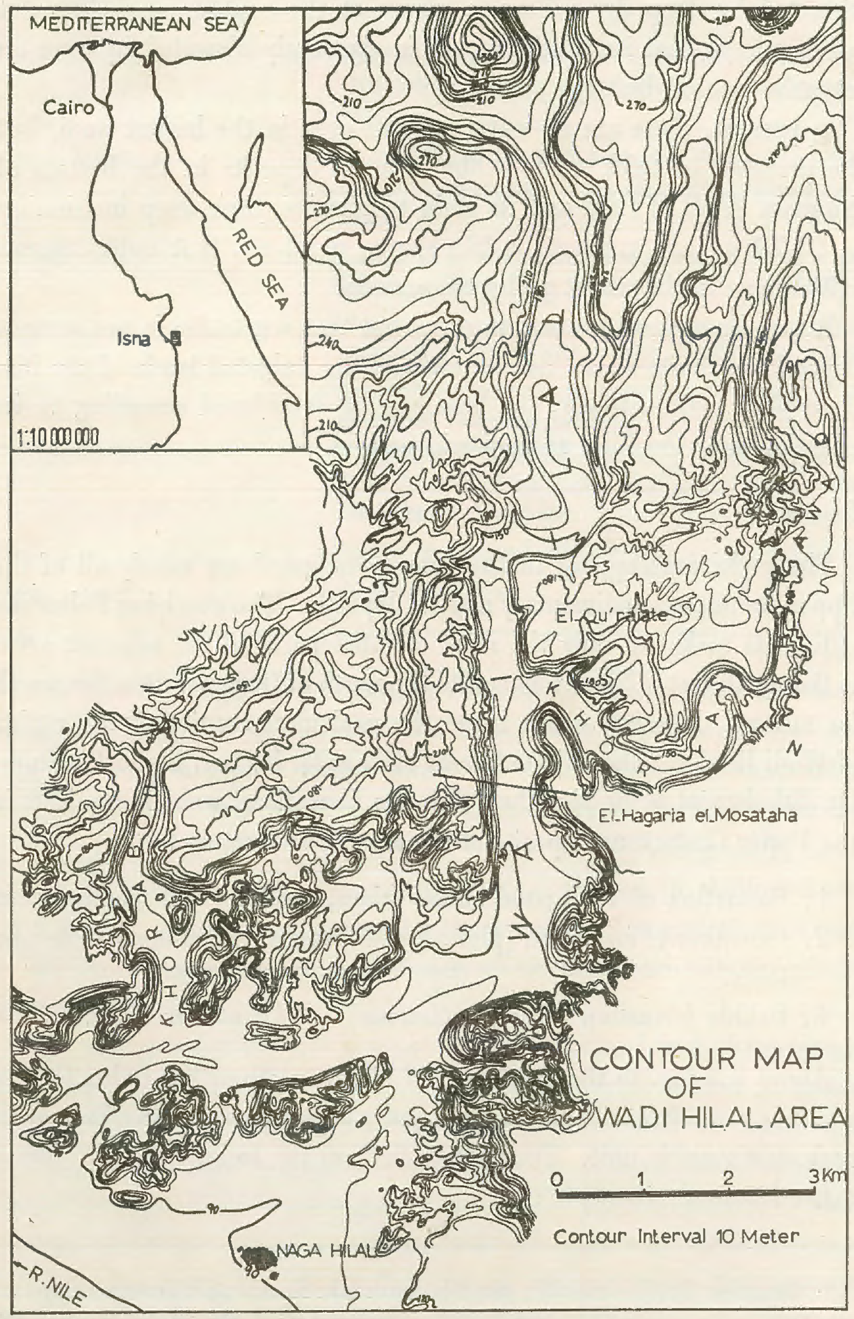

Fig. 1.

dissected by deep dry valleys, a glance at the contour map does not fail to realise that its southern part is vigorously dissected by once an intensive net of drainage system.

At present, there are no water streams even in the largest wadi, but the presence of thick sandy-pebble alluvial deposits in the bottom of the main Wadi of Hilal and its main tributaries, their deep incision-up to 60-70 meters, and canyon-like shape, point out that water-streams existed here in the recent geological periods.

It may be of some interest to point out that vegetation is not present beyond the limits of the narrow strip of the irrigated lands of the Nile flood-plain. Climatically, the area can be considered according to its situation near the Nile, as semi-arid or arid.

Geology :

The rocks outcropping in the area investigated are nearly all of the Upper Cretaceous sedimentary marine deposits. The overlying Paleocene sediments make up only the most elevated parts of the adjacent areas to the northwest of Sharawna and to the north of Qurayat. It is the search for mineral deposits, which made the geological studies of the region of Wadi Hilal and the adjacent areas start as far back as the last century. On lithological principle, the following formations were recognized in the Upper Cretaceous deposits of the area (from bottom to top).

1. Formation of Variegated shales (clays, sands) — 60 meters thick.
2. Phosphorite formation (phosphorites, marls, limestones) — 4-6 m. thick.
3. Dakhla formation (clayey sediments) — 140 meters thick.

About 8.5 km. to the north-east of Sibaiya station, lies Gabal Oweina which is c. 450 m. above sea-level and which represents the Esna shale rock stratigraphic unit. The succession from top to bottom is as follows (after Beadnell, 1950) [1] :

[1] Beadnell, H.J.L. (1950) : The relations of the Eocene and Cretaceous systems in the Esna-Aswan reach of the Nile Valley, *Quart. J. Geol. Soc. of London,* Vol. 61, pp. 667-678.

Thebes Formation (Ypresian)	9. — Hard limestone with chert concretions containing Operculina Libyca, Nummulites praecursor, and others.	20 m.
Esna Shale	8. — Laminated green and grey shales.	60 m.
Chalk	7. — White (weathering brown) bedded marls and chalk.	20 m.
Dakhla Shale	6. — Green and blue laminated shale with a white limestone band.	100 m.
	5. — White to grey marl with ferruginous bands crowded in places with Pecten farafrensis.	8 m.
	4. — Laminated grey and iron-stained shales with abundant limonitic cossils.	
Phosphate Formation	3. — Hard oyster limestone capping intimately-associated bone and coprolite bed with Ostrea villei, sometimes phosphatic.	4 m.
Variegated shales	2. — Sandy shales and siltstones.	45 m.
Nubia sandstone	1. — Sandstone beds.	?

The basal transgressive beds that covered the peneplained basement rocks are composed of virtually non-fossiliferous Nubia sandstone and the overlying variegated shales which are vividly coloured shales alternating in places with some sand and siltstone beds. It seems that the Nubia sandstone, made essentially of coarse to medium-grained sandstones with minor shale intercalations was deposited in shallow transgressive sea. This was followed by the breaking down of this sea into a system of lagoons of brackish-water where thick vari-coloured shales were deposited.

The variegated shales are overlaid by a well-defined unit characterized by the presence of number of phosphatic bands interbedded in marls, shales, silicified limestones, and bands of Ostrea villei. It seems that the lagoonal conditions which prevailed over Egypt during the deposition of the variegated shales changed at the end of the campanian or early Maestrichtian time into a bay connected with open sea. This bay must have an oceanographic set up that stirred strong currents that abraded the sea bottom and reworked its sediments. The deposition of the phosphate beds is linked with the action of these strong currents.

On the top of phosphate formation follow the Dakhla shales which are of remarkably lithological characteristics. They consist of a lower part, rick in calcareous marls (so-called Pecten marls), and an upper shale part. In the vicinity of the area of Wadi Hilal as it is at Gabal Oweina, the unit assumes a thickness of c. 140 m.[1].

This succession of the upper Cretaceous rocks and Paleogene sediments are generally overlain by Quarternary sediments. There are alluvial, talus-proluvial and alluvial sediments among them. The sediments can be divided into :

a) Lower Quartertary, probably partially Late Neogene $(N_2\text{-}Q_1)_1$ represented by the conglomerates or slightly cemented loam and loam-pebbled proluvial-alluvial deposits. They are rather wide spread in the northern part of the present area and occupy relatively high hypsometric position forming thick cover (30-40 m. or more) overlying the various horizons of the Dakhla formation (See Pl. I).

b) Lower and Middle Quarternary sediments $(Q_1\text{-}2)$ include the alluvial sand-pebble sediments.

c) Upper Quarternary-Recent sediments (Q-3-4) include loose alluvial sediments of the young terraces of the Nile as well as the talus-proluvial sediments of slopes and wadis.

The area of El-Mahamid deposit structurally is included into the so-called «Stable Shelf» of the African Platform. Almost horizontal occurrence of rocks with a very gentle general plunge (1°-1,5°) north-westwards is typical of the abovementioned Cretaceous and Paleogenex sediments. There are also inextensive tectonic dislocations similar to faults of low amplitude, mainly of north-western trend [2]. (See the Geological Map Fig. 2).

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[1] Said, R. (1962) : The Geology of Egypt, *Elsevier,* Amsterdam and New York, pp. 127-134 and pp. 92-93.

[2] Report on the Results of Geological Exploration at the El-Mahamid Phosphorite Deposits. Carried out in 1966-1968. Vol. 1. Egyptian General Organisation for Geological Research and Mining, pp. 17-18.

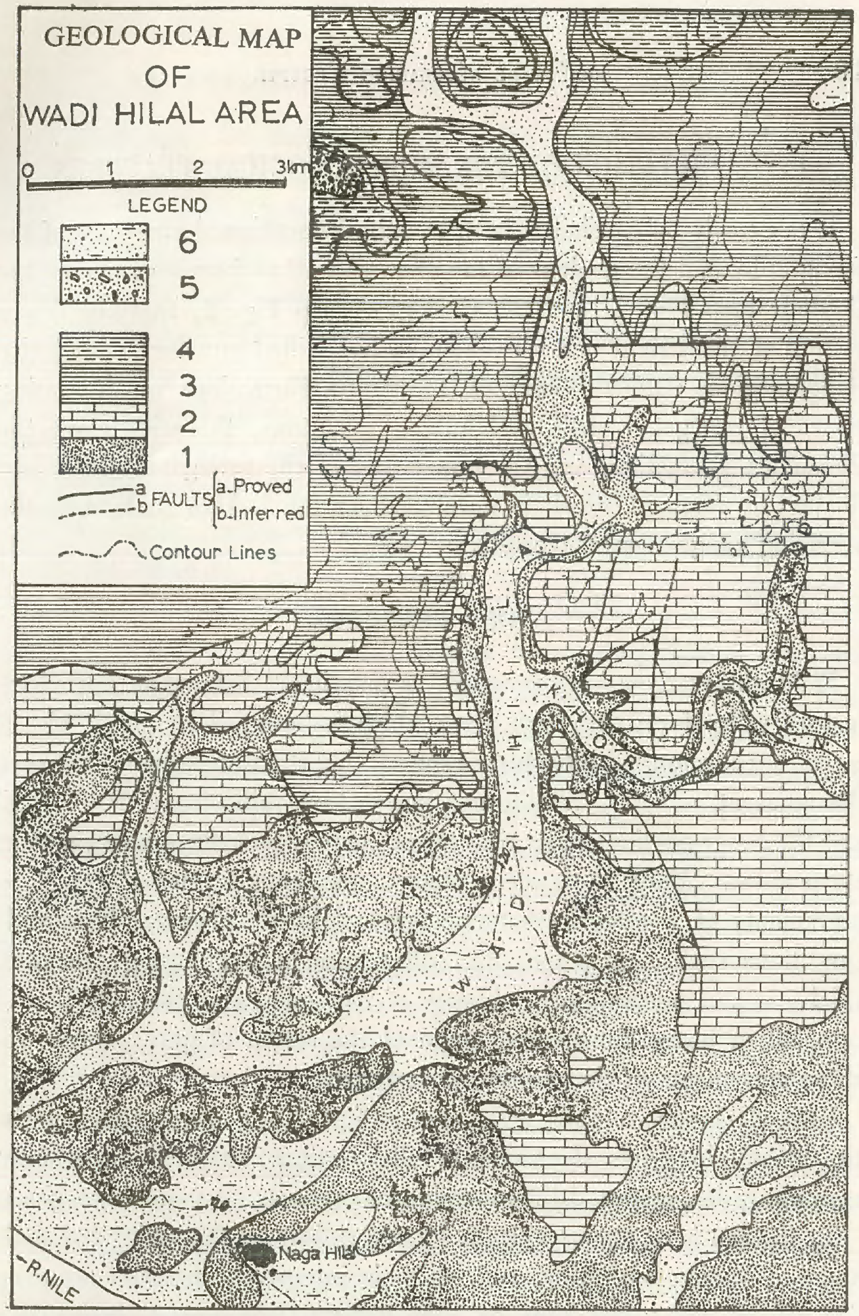

Fig. 2.— Key of the Geological Map.

6 Alluvial and Proluvial deposits. Loams, mud, pebbles and sands.
5 Alluvial and Proluvial deposits. Quartz sands, gravels and Conglomerates, Limestone blocks, Covering high watersheds.

Dakhla Shale Formation

4 Upper subformation. Clays, dark grey, with bands of chalky limestone and marls.
3 Lower subformation. Clays, dark grey.
2 Phosphate formation. Clays, phosphates, marls and Oyster limestone.
1 Nubian formation. Variegated shales, silty clays, Siltstones and sandstones.

INTERPRETATION OF THE MORPHOLOGICAL FEATURES

It can easily be concluded from the above mentioned summary of the topography and the geology of the area, as well as from a glance at the Contour map Fig. 1, and the Geological map Fig. 2, that the lower section of Wadi Hilal can, conveniently, be divided into three distinctive minor regions : the southern on the Nubia Formations of alternating layers of variegated shale and nubian sandstone, the middle on the Phosphate Formations and the upper part of the variegated shale, and finally the northern which is developed on the Dakhla shale with the overlying conglomerate deposits.

SLOPE FEATURES

Field observations have revealed, as mentioned before, an open late-mature valley form with wide floor which is bounded by gentle slopes ascending to rounded interfluves representing the water-divides between the adjacent valleys. Within this late-mature valley-form, Wadi Hilal and the lower portions of its tributaries incise deep valleys with vigorous steep sides. Along these steep slopes, numerous forms of downslope movements of weathered materials are exhibited. Several favourable conditions, such as steep declivities ; alternating beds of varying resistance, thickness and permeability ; absence of vegetation and concentration of rain fall in heavy downpours, augment the action of gravity in down-slope movements of the weathered materials.

Since all these conditions, with the exception of the geological characteristics, prevail along these steep sides of valley sections, distinctive mass movements have demonstrated differently in each of the above postulated regions.

In the southern region which is formed mainly on the variegated shale and the Nubian sandstone, and which is intensively dissected by deep dry valleys, the valley rims on both sides appear pyramidic in their form, with vertical rock face coinciding with hard band of sandstone at the base and a gentle slope on the shale above. But where the shale cover is removed (eroded), slabs of Nubian sandstone characterize the spurs of the tributary valleys of Wadi Hilal with rock fragments at the foot slopes. On the other hand, steep rock faces coinciding with interbedded hard bands of sandstone with gentler slopes above and below, reflect the lithological influence on the slope type in this region (Pl. II A).

Moving northwards to the middle region, where the Phosphate Formation overlies the upper part of the variegated shales, it not difficult to recognize the hard band of Oyster limestone standing as a free vertical rock face surrounding the deeply incised middle section of Wadi Hilal. Since the general dip is towards the north-west, the Oyster band and the associated feature eventually declines in altitude on the valley-sides in this direction till finally disappears below the valley-floor in the northern section, where it is represented in a cascading lithological knickpoint. (Map Fig. 3 and Pl. III A).

The slopes on the variegated shales below the Oyster band is mostly uniform and constant, but where a hard band of sandstone outcrops on the valley-side, it exhibits a steep slope with gentle slopes above and below. It has been noticed here that the shale slopes below the Oyster band are covered with broken «flakes» derived from the retreating of the rock-face developed on this limestone band. This feature is magnificantly developed on this shale slopes of the dry valley tributaries along this portion of Wadi Hilal, as well as the area of rejuvenation of Khor Awad where it cut its lower section in the Oyster limestone and the variegated shales below. The lower valley of Khor Awad below the knickpoint on the Oyster limestone (Map Fig. 3) is without flat valley-floor, and the slopes below the old valley-floor are entirely covered with the broken and collapsed «flakes» of the Oyster limestone (Pl. III B).

The northern region is carved, as it is pointed out, in the Dakhla shale and the conglomerate deposits on the top. Here the slope features are different from those in the middle and the southern sections. The ground exhibits gentle constant slopes with slight convexity and concavity segments above and below respectively. The slopes on the Dakhla shale underlying the conglomerate are strewn with boulders and gravels derived from the conglomerate after it is weathered.

One more significant feature and which deserve consideration is the intimate relationship between the process of landsliding phenomena and the process of undercutting associated with the convex side of the dry

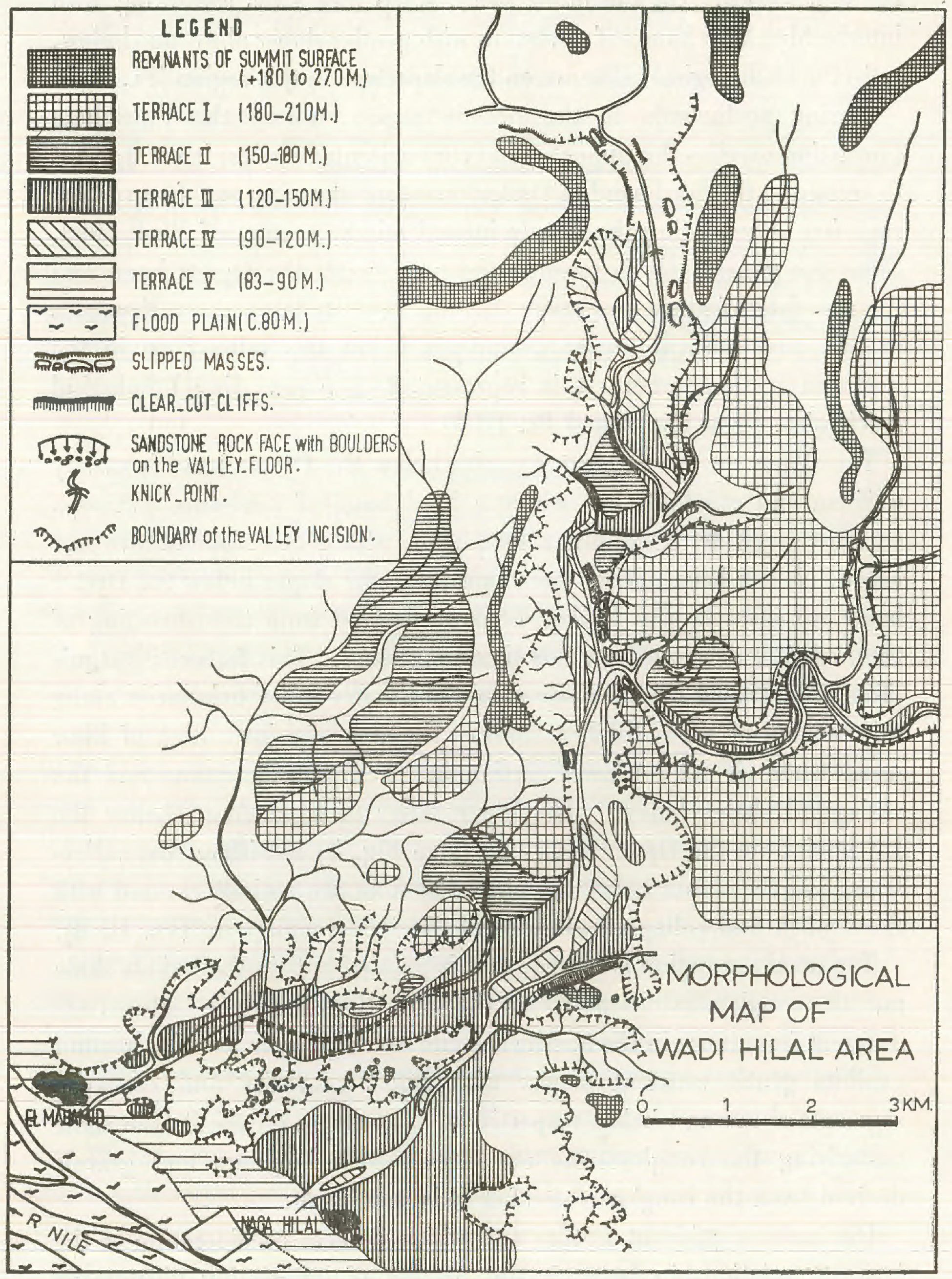

Fig. 3.

channel meander during the periods of heavy rain downpours. It is evident that the steep segments of slope are always developed where the channel meander lies at the base of the valley side. It is noticed that undercutting is responsible for most of landsliding features occurred along the valley sides. Where landsliding occurs, it can be taken as an indication of an old position of a channel meander, even when the meander is not there at present. In the northern section of the area an almost vertical slope developed on the Dakhla shale is due to process of undercutting (Pl. I). In the lower section of Khor Yassen, the effect of undercutting is well-represented by landsliding and slumping of hard rocks due to the removal of the soft formations of shale below by this process (Pl. IV B). The morphological map fig. 3, shows the types of landslides and related phenomena observed in the field.

Although the levelled section across Wadi Hilal along the line shown on map fig. 1 reveals the lithogical effect on the valley sides, it is however clear that there is — as shown on the eastern side — a bevelled surface developed on both variegated shale and the Nubian sandstone at c.150 ms. above sea-level and about 30 meters above the present valley-floor.

VALLEY TERRACES

The high degree of dependence of the visible topographic features on the underlying geology that has been previously discussed, may readily lead to the complacement belief that the landforms within the lower section of Wadi Hilal can be wholly explained in terms of the nature and disposition of the rocks. Field investigations have, however, shown that although the structural features are individually not explicable in terms of regional base-level, large features which possesses sufficient uniformity of character occur over a sufficiently large area as to suggest that they represent major stages in the evolution of the land surface. The features in question are the base-levelled surfaces (erosion surfaces).

By observing and analysing the surviving scattered remnants of the former valley-floors over the whole of the area of study and by correlating them in the field, a sequence of erosion surfaces has been established, ranging from the height of c. 300 meters down to the height of the

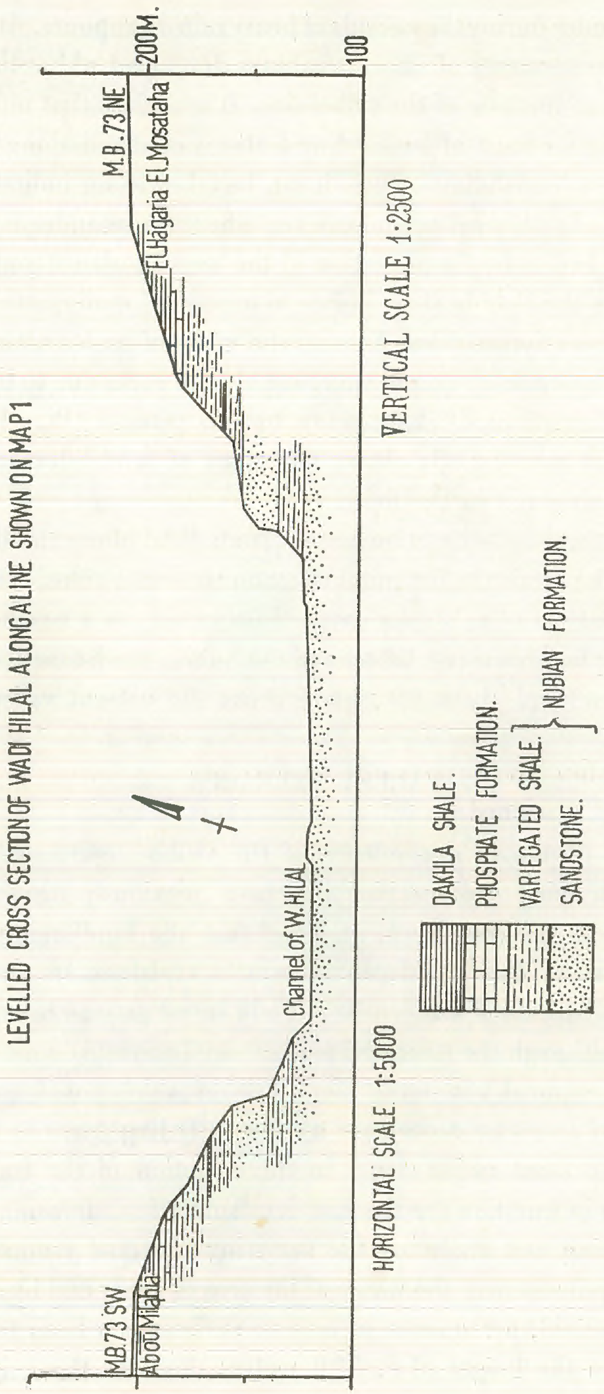

Fig. 4.

present flood-plain of the Nile which is about 80 meters above sea-level. The morphological map, Fig. 3' shows the distribution of these remnants which can be tabulated as follows :

SURFACE		HEIGHT OF FRONTAL BREAKS IN METERS ABOVE SEA-LEVEL
Summit Surface		+ 180 to c. 270
Terrace	1	180 to 210
Terrace	2	150 to 180
Terrace	3	120 to 150
Terrace	4	90 to 120
Terrace	5	83 to 90
Flood Plain		C. 80

On these level, the «Summit Surface» and «Terrace 1» are preserved in the higher section of the composite valley form and where Terrace 1 represents a valley-floor above well developed knickpoints below which the tributary valleys of Wadi Hilal are deeply incised, i.e. Khor Awad and Khor Abou Malahia. Remnants of this floor appear as «flats» above the steep slope bounding the main valley of Wadi Hilal on both sides; These «flats» are backed by gentle slopes ascending to the «Summit Surface». Since these remnants of both the «Summit Surface» and Terrace 1 are developed on different rock types-on the Dakhla shale and Phosphate formations as well as on the Nubian formations, they may be considered erosional and not structural features, a view which is supported by the gravelliverous deposits of thickness varying from 20-30 cms. on their surfaces.

The rest of the levels mapped in the field are well preserved along the deeply incised sections of Wadi Hilal and its major tributaries. (Map Fig. 3). A conspicuous flat surface (Terrace 2) is well developed on the variegated shale on the interfluve lying between Wadi Hilal and a tributary dry valley in the vicinity of Mine No. 2 in the middle section of the area of study. This surface is covered with c. 130 cms. of coarse gravels and sand (Pl. V). Below the remnants of this terrace there is a clear vertical incision of about 10 meters leading downslope to a series of three well-developed gravelliferous terraces represented by «Terrace 3», «Terrace 4» and «Terrace 5» above the present flood-plain of the Nile.

It is noticed that the vertical heights separating these terracettes are very slight varying from one meter to c. two meters; and the bedrock underneath the deposits does not appear on the surface of the ground (Pl. VI).

These gravel terraces may correspond with «High», «Middle» and «Low» gravel terraces in Kom Ombo Basin as indicated by K.W. Butzer and C.L. Hansen [1]. In Wadi Abbadi Butzer and Hansen in 1963, found the low terraces at + 5 meters and + 10 to + 12 meters (relative to Wadi floor), an intermediate terrace at +21 meters and a high terrace at + 43 meters. The low terraces are fully comparable to the Low Terrace complex of Kom-Ombo, the two higher terraces can be traced downstream, with the well-preserved intermediate terrace graded to a Nile flood-plain of about 115 meters (83 ms. today). With a relative Nile elevation of 32 meters, this intermediate terrace is probably equivalent of the Middle terrace. The higher terrace subdivides near the mouth of the Wadi, where it is recorded on the southern side at 125 ms. (+ 42 m.) and at 135-137 meters (+ 52 to + 54 m.), a remarkably close correspondance to HT II and HT I at Kom Ombo [2].

In the Luxor area, a well known 9-10 meters Wadi Terrace (relative to Wadi floor) is well preserved. In the lower section of Wadi Qena, a terrace sequence indicates the presence of extended gravel terraces graded to successive flood-plain levels at about + 70, + 51, + 34, and + 23 meters, with one or more lower, less significant stages. The altimetric and Geomorphic correspondence with Gallaba stage, HT I, MT, and LT I at Kom Ombo needs little emphasis [3].

The gravel terraces observed in the lower section of Wadi Hilal may therefore be correlated with the terraces observed in the area of Kom-Ombo and the major dry valleys ending to the Nile, either to the south or to the north of the area of Wadi Hilal, as follows:

(1) K.W. Butzer and C.L. Hansen (1968): Desert and River in Nubia. Geomorphology and Prehistoric Environments at the Aswan Reservoir, pp. 52-63. The University of Wisconsin Press 1968, London.

(2) *Ibid.*, pp. 63-64.

(3) *Ibid.*, p. 65.

(1) *Geomorphic Evolution of Wadi Hilal Area and the Adjacent Areas during the Late Tertiary and Early to Middle Pleistocene*

WADI HILAL	KOM OMBO	WADI ABBAD	LUXOR AREA	WADI QENA	AGE
T 5 (+ 3 to + 10 m.)	LT 2 (+ 15 m.) LT 1 (+ 22 m.)	+ 5 m. T + 10 to + 12 m. T + 32 m. T	+ 9 to + 10 m. T	+ 23 T.	Middle Pleistocene
T 4 (+ 10 to + 40 m.)	MT (+ 34)			+ 34 m. T	
T 3 (+ 40 to + 70 m.)	HT 2 (+ 40 to + 43 m.) HT 1 (+ 51 to + 54 m.)	+ 42 m. T (52 to + 54 m.) T		+ 51 m. T	Lower Pleistocene
T 2 (+ 70 to + 100 m.)	Gallaba Stage (+ 60 to + 74 m.)			+ 70 m. T	Basal Pleistocene
T 1 (+ 100 to + 130 m.)	Pliocene regressive deposite to 130 m. elevation.				Upper Pliocene
	Bedrock dissection and minor tectonic deformation.				Lower Pliocene
Summit Surface (+ 100 to 190 m.)	Lateral planation with development of Aswan Pediplain. Local base-Level a little below 180 m.				Mio / Pliocene
Present Flood Plain Level above Sea Level					
C. 80 m.	C. 89	C. 83 m.	C. 75 m.	C. 73 m.	

N.B. — The heights of the Terraces are relative to the present flood-plain level.

(1) Compiled from: Butzer, K.W., Sandford, K.S., Sandford, K.S. and W.J. Arkell — See the list of References.

THE CAPTURE GAP

In the southern region of the area of study, there is a conspicuous old water-gap, through which, Wadi-Hilal breaks to join the Nile, just below Naga Hilal. Field observations show that the high ground embraced by the two branches of the lower section of Wadi Hilal and which lies at a level of about + 200 meters above sea-level was once connected with the northern (opposite) side of the gap, which represents the southern end of what is known by «Haggaria El-Moussattaha» and which stands at a similar height. The gap is incised deeply in sandstone and shales belonging to the Nubia Formations with two gravel terraces (T 3 and T 4), the remnants of which are well represented on the Nile side, while Terrace 4 does not exist on the side of the deserted Wadi El-Mahamid. These terraces are backed by intensively eroded slopes exhibiting clear examples of rock-fall and landsliding. For a distance of about half kilometer, the gap is very narrow and it opens afterwards to an extensive bay-like flat area at a level of more than 100 meters above sea-level sloping gently towards the cultivated flood-plain of the Nile. On the Nile side of this gap the floors of the dry valley tributaries discharging into the Nile overlooks Terrace 4 with steep incision and appear as hanging dry valleys. In the middle of this gap, an outstanding stack-like rock has been observed (Pl. VII, A-B), which gives the person approaching it through the gap the impression that he is approaching a well-developed stack (needle) on coastal beach.

These features, as well as the absence of Terrace 4 along the north deserted branch of Wadi Hilal, may give an explanation to the origin of this gap as well as its dating. The floor of the deserted branch of Wadi Hilal (Wadi El-Mahamid) corresponds with Terrace III and represents a floor of a wind Gap. These evidences may indicate river capture in this area, which may be due to normal struggle between two tributary streams flowing in different directions and lowering their resourse-area with the result that the Nile tributary diverted the main course of Wadi Hilal to flowing through this gap. The landform configuration may, however, give an alternative explanation. When the Nile was at a higher

Fig. 5. — The Gap through which the Present Day Channel of Wadi Hilal joins the Nile.

level coinciding with that of Terrace 3, a large convex meander was active in undercutting the flood-slope overlooking the Nile, especially during the flood periods. In the meanwile a convex channel or Wadi Hilal was doing the same task on the opposite side. The meeting of the two meanders has produced the present landforms on both sides of the gap, particularly the amphitheatre-shape of the high ground facing the Nile and overlooking the floor of Wadi Hilal. It may be deduced that this morphological incident has happened after the formation of Terrace 3.

CONCLUSION

This investigation of the geomorphological features of the lower section of Wadi Hilal, has enabled certain conclusions to be made. The topography of this section is largely influenced by the underlying geology but a sequence of erosion surfaces has been recognised. The distribution of these surfaces may suggest that this area initially underwent a long period of base-levelling, the result of which was the development of the «Summit Surface». This was followed by negative movement of base-level and a shorter still-stand allowed the development of Terrace I. This still-stand was succeeded by further falls of base-level separated by phases of relative stability, which have resulted in the production of the valley terraces exhibited within deeply incised section of the Wadi-Hilal below Terrace I.

According to the studies carried out in the adjacent areas, the summit surface can be related to Mio-Pliocence, Terrace I, to Upper Pliocene while the rest of the terraces are developed since the Pleistocene.

A new type of capture which may be termed «Meander Capture» is well represented by the gap developed in the southern region of the lower section of Wadi Hilal.

Subject : Readings of the Levelled Cross Section of W. Hilal (Section Line is shown on map, Fig. 1) M.D. 73 NE to 73 SW.

Stn. : «A» H.I. : 1.55 M Stn L. 121.72 M

Theod. No.	Circles Horiz. C.	Circles Vert. C.	Staff Read. H.W.	Staff Read. M.W.	Staff Read. L.W.	Slope Dist.	Horiz. Dist. Meter	H Meter	R.L. Meter
1	00” 00’ 06”	+10” 01’ 47”	3.83	2.00	—	366	354.91	+63.89	185.44
2		+10 14 40	3.75	2.00	0.25	350	338.94	+62.32	183.87
3		+ 9 34 48	3.66	2.00	0.34	332	322.83	+55.26	176.81
4		+ 8 53 54	3.41	2.00	0.59	282	275.26	+43.59	165.14
5		+ 7 59 26	3.27	2.00	0.73	254	249.07	+35.35	156.90
6		+ 4 05 38	3.20	2.00	0.80	240	238.80	+17.04	138.59
7		+ 2 15 42	2.93	2.00	1.07	186	185.70	+ 7.29	128.84
8		-00 23 30	2.85	2.00	1.15	170	170.00	- 1.19	120.30
9		-00 31 38	2.78	2.00	1.22	156	156.00	- 1.45	120.10
10		-00 24 02	2.76	2.00	1.24	152	152.00	- 1.06	120.49
11		-00 48 02	2.57	2.00	1.43	114	114.00	- 1.60	119.95
12		-01 14 50	2.35	2.00	1.65	70	69.96	- 1.50	120.05
13		-00 49 46	2.30	2.00	1.70	60	60.00	- 0.87	120.18
14		-00 56 26	2.27	2.00	1.73	54	54.00	- 0.88	120.67
15		-02 00 34	2.14	2.00	1.86	28	27.96	- 0.97	120.58

Subject : Readings of the Levelled Cross Section of W. Hilal (Section Line is shown on map Fig. 1) M.D. 73 NE to 73 SW.

Stn. : «A» H.I. : 1.55 M Stn L. 121.72 M

Theod. No.	Circles Horiz. C			Vert. C.			Staff Read H. W.	M. W.	L. W.	Slope Dist.	Horiz. Dist. Meter	H Meter	R.L. Meter
16				—	—	—	2.32	2.21	2.10	22	22.00	0.00	121.45
17	180	00	06	—	—	—	1.59	1.56	1.53	6	6.00	0.00	121.99
18				—	—	—	2.75	2.69	2.63	12	12.00	0.00	120.86
19				—	—	—	2.60	2.29	1.98	62	62.00	0.00	121.26
20				—	—	—	1.68	0.63	—	210	210.00	0.00	122.92
21				+00	37	28	3.08	2.00	0.92	216	216.00	+ 2.33	123.88
22				+00	50	32	3.27	2.00	2.54	254	254.00	+ 3.68	125.23
23				+03	09	40	3.40	2.00	2.80	200	279.16	+15.37	136.92
24				+05	10	40	3.44	2.00	2.88	288	285.66	+25.83	147.38
25				+06	00	35	3.50	2.00	0.50	300	296.73	+31.02	152.57
26				+05	55	16	3.56	2.00	0.44	312	308.69	+31.88	153.43
27				+05	49	00	3.83	2.00	0.17	366	363.28	+36.78	158.33
28				+06	29	34	3.88	2.00	0.12	376	371.18	+42.30	163.85
29				+08	17	00	3.12	1.00	—	424	415.18	+60.42	182.97
30				+08	11	53	3.18	1.00	—	436	427.14	+61.56	184.11

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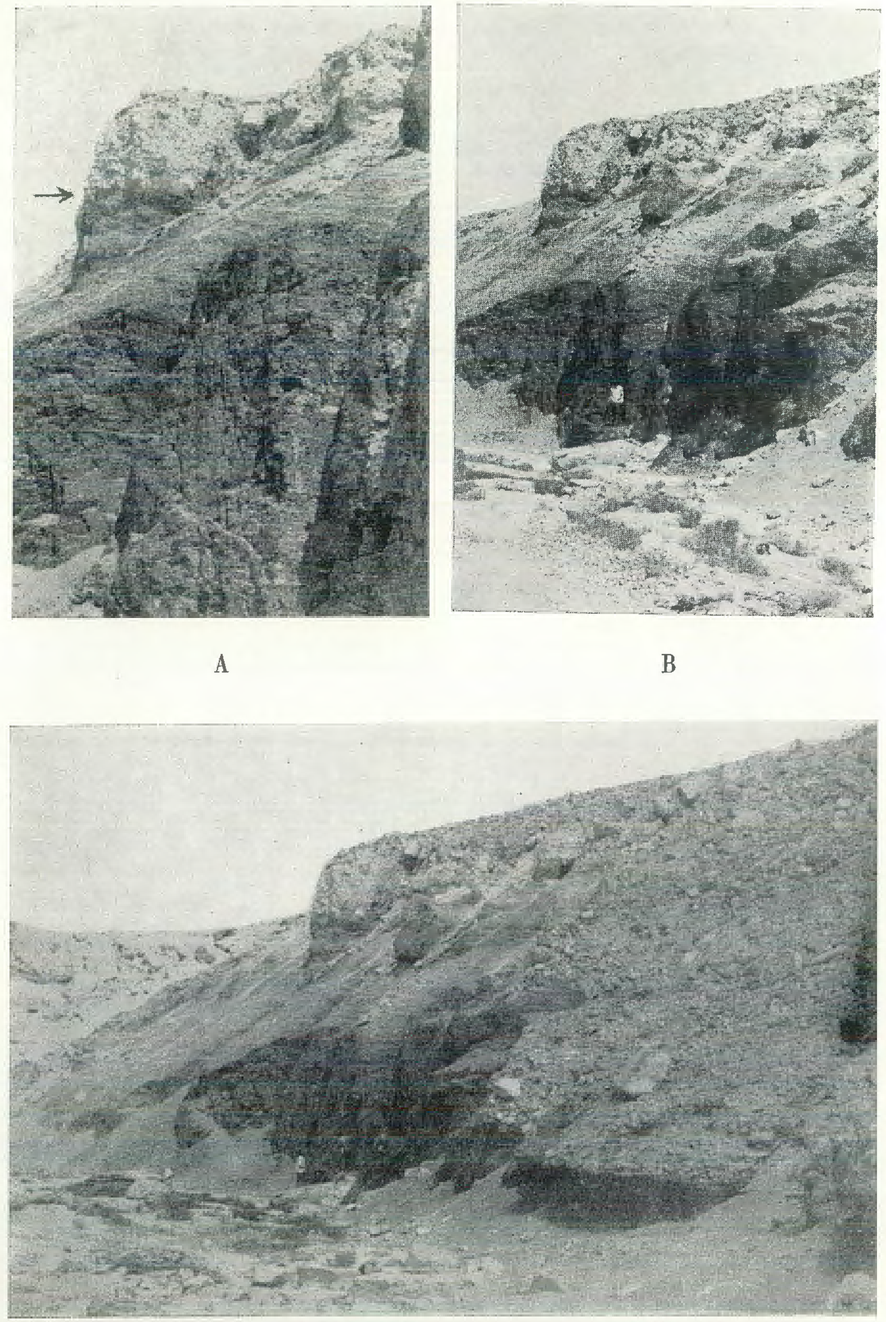


A B

C

A series of Photographs illustrating :

A-B. — The Conglomerate overlying the Dakhla Shale underneath.

C. — The effect of the undercutting on the slope developed on the Shale.

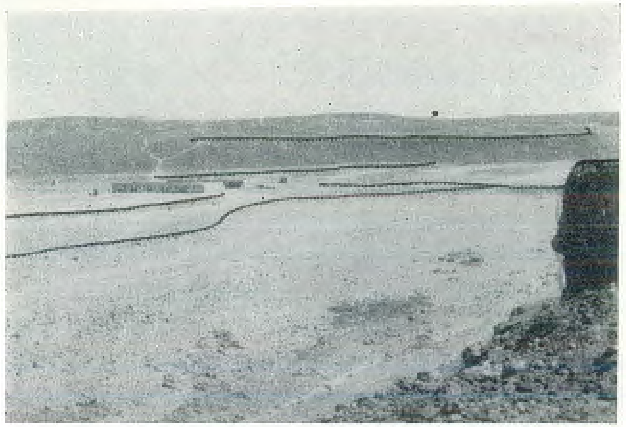
A. — Panorama showing the southern side of the Valley of ' Khor Yassen ' near its confluence with Wadi Hilal.

Notice the steep slope on the Nubian Sandstone just above the valley-floor, the gentler slope above it on the variegated shale and the Oyster band appears at the top of the slope as a dark shading above the variegated shale, The sky-line represents the surface of ' El-Hagaria el-Mosataha.

B. — The gentle slope developed on the Dakhla Shale.

A. — Illustrating the sequence of Phosphate formation on the floor of Wadi Hilal to the north mining area (the upper section of the valley shown on Map I). It represents a rejuvenational Knickpoint at a level of c. 160 m. coincides with that observed in Khor Awad at about the same level (the last is about 10 m. higher due to the dipping of the formation towards the north west).

B. — Shows the Knickpoint in Khor Awad on the Oyster limestone. Notice the open valley above the Knickpoint.



A

B

C

A. — Showing a sequence of the terraces along the valley side of Wadi Hilal in the mining area. The Sky-line represents the summit-surface.

B-C. — Illustrates the sliding of Nubian sandstone on the slopes developed on the variegated shale underneath in Khor Yassen near its confluence with Wadi Hilal.

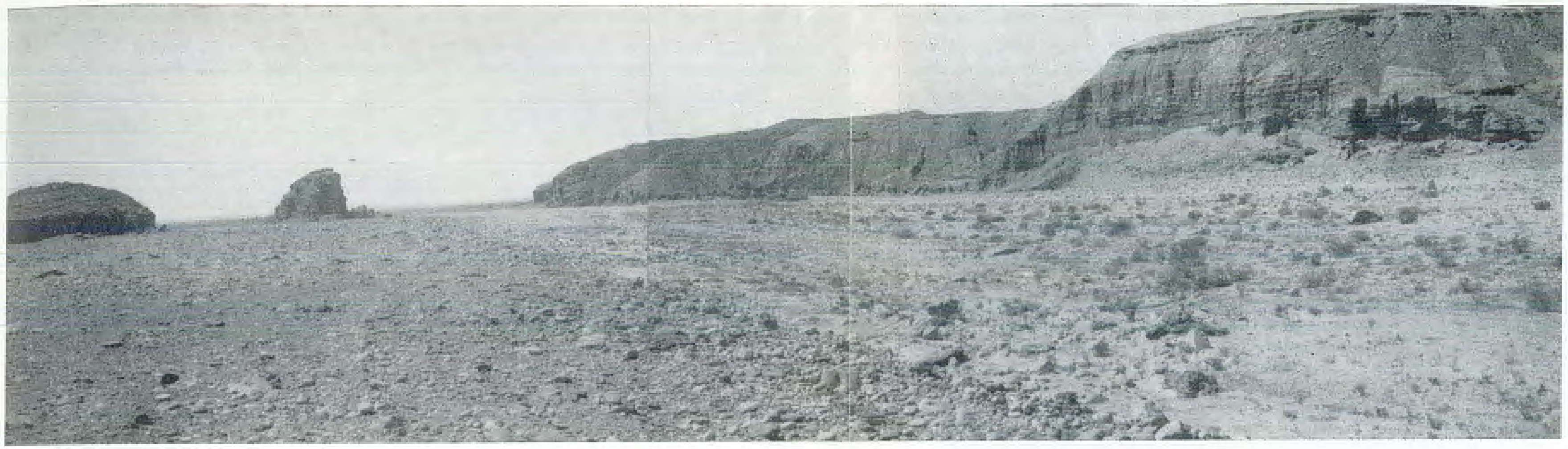
A. — Deposits of sand and gravels of Terrace 3 in the upper section of Wadi Hilal. Notice the difference in the steepness of slopes developed here on the Dakhla Shale and those developed on the variegated shale and the Nubian Sandstone in Plate VII, B.

B. — Dakhla shale covered by the gravels of Terrace No. 2 on the top of Mine No. 1 in the Mining Area (c. 180 m. above Sea-Level).

A

B

Shows the gravellavreous deposits of Terrace 3 at the difluence of the new channel of Wadi-Hilal.

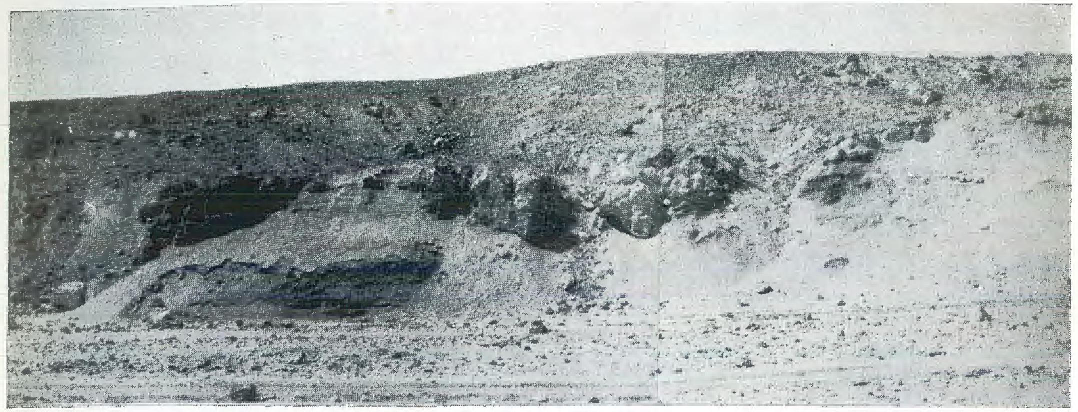


A. — Panorama showing the ' Gap ' through which the new course of Wadi Hilal joins the Nile. The top surface (sky-line) is a remnant of the ' Summit Surface ' in the southern part of the area.

B. — Series of Photographs approaching the Nile Flood Plain through the Gap of the New course of Wadi Hilal. Notice the rock fall on the right side of the ' Stack-like ' Rock made up of Nubian Sandstone.

A. — Panorama showing the incision of Khor Awad just below the Knickpoint and the slopes covered with 'flakes' of the Oyster Limestone which is shown in the picture as a dark band separating the open valley above and a deeply incised one below.

B. — Shows the slopes covered with Oyster fragments just below the Knickpoint in Khor Awad (c. 180 m. above Sea-Level).



A. — Panorama showing the sliding of the Conglomerate on the Dakhla Shale below.

B. — Illustrating the sliding of the Conglomerate of the slope developed on the Dakhla Shale underneath.

A. — The Channel of Wadi Hilal with boulders of Conglomerate origin, carried by water during torrential rainfall in the upper section of the Wadi.

B. — A piece of the Oyster limestone in the channel of Wadi Hilal showing the chemical weathering on the side facing the current of water, the feature is not clear on the opposite side. Notice the gravels accumulated in front of the weathered side while fine materials (deposits) of sand and silt are deposited on the other side.

CHARACTERISTIC AND EVOLUTION OF THE DRAINAGE PATTERN IN THE MAGHARA DISTRICT-NORTHERN SINAI U.A.R.

BY

HASSAN ABOU EL-ENIN

M. A., PH. D.

The Maghara District is an area of about 1700 square kilometres and lies in the northern part of Sinai. However the examined area is only 200 square kms. It is situated about 150 kms. east of Ismailia, and 90 kms. to the southwest of El-Arish. It varies in height from 250 metres O.D. within the floor of the Masajed Basin, in the northwestern part of the area, to about 730 metres O.D. at the top of Shusht el-Maghara in the southeast. The area has been geomorphologically investigated by the author during the course of the summer field-work in the year 1965. In 1966 a paper was published by the author about the development of cuestas and other structurally controlled features within the area under examination. The present paper, however, is dealing with the characteristic and evolution of the drainage pattern within the same area.

According to the Davision concept of the cycle of erosion the maximum adjustment of drainage to structure occurs at a late stage. One, therefore, would expect the structural pattern, to be most evident in the relief at that time. Since the surface configuration of the Maghara District is generally considered to have been morphographically modified under pluvial and arid conditions of the Pleistocene, (Abou el-Enin, 1966, p. 191); most of the drainage's segments are not fully adjusted to structure. Therefore, before reviewing the evolution of the drainage pattern it is useful to summarise the general lithology and structure of the rocks of the area under examination and to point out the characteristic and geomorphological significance of the drainage's segments of the area, since the latter is in part the reflection of the former.

I. — GENERAL GEOLOGY OF THE MAGHARA DISTRICT.

The rocks of the area under consideration are mainly members of the Jurassic formation. Their total thickness, in this locality, amounts to about 1905 metres. (Arkell, 1956, p. 307). The Coal-Measures, are the oldest rocks in the area, and are restricted to the Bathonian and Bajocian Stages (Middle Jurassic). Examination of the lithological, characteristic of the Coal-Measures within the Safa Area, indicates that they are lagoonal and/or deltaic-continental facies. They are composed of two beds of coal, separated by shale bands, with intercalations of marls, outcropping in the vicinity of Shusht el-Maghara. The Coal-Measures are overlain by dark sandstone beds with intercalations of shales and marls, and are all capped by a Flinty Limestone which is a useful marker of the contact between this stage and the overlying Callovian, Oxfordian and Kimmeridgian Stages of the Upper Jurassic. The Geological formation of the latter is mainly composed of shales, marls, chalky limestones, and subordinate bands of sandstones which are all of about 350-400 metres in thickness. These upper Jurassic sediments are of shallow marine facies.

Cretaceous rocks are well exposed to the north and western part of the Jurassic formation of Gebel el-Maghara. The lower members of the Cretaceous sediments (belonging to the Aptian and the Albian Stages) are mainly composed of fossiliferous varicoloured shales, grits and sandstones with intercalations of brown fossiliferous limestone. The latter band can be observed on the steep slopes of Gebel Barga. While the formations of the Middle and Upper Cretaceous Stages (Cenomanian, Turonian and Santonian Stages) are well exposed immediately to the southeast of Gebel el-Maghara, and are generally formed of chalky and sandy limestones. The Maghara District is deeply dissected by wadies (dry valleys) partially filled with unconsolidated or loosely unconsolidated sediments of Pleistocene and Holocene in age. Most of these wadies in turn, flow into the Masajed Basin. The latter is covered with a thick blanket of deposits (about 30 to 40 metres in thickness), mainly

composed of extensive sheets of sands, clays and silts. Boulders, gravels, cobbles and pebbles are scattered, here and there, on its surface.

The tectonic structure of the Maghara District has in the one hand influenced the drainage system and it explains, on the other, the pattern of the solid rock-outcrops. The dip and strike of the rocks and fault planes, influence the surface configuration, surface forms and the initiation and subsequent development of most of the drainage's segments. The rocks of the Maghara District are affected, in some way, by the Alpine Orogenesis, which produces two parallel anticlines separated by a narrow shape syncline. The greater anticline is centered at Shusht el-Maghara, while the lesser one runs through Gebel Hamayir to the west of Gebel Maghara and Gebel Um-Mafrouth to the northeast.

Structural contours of the inlier of Gebel el-Maghara indicate that the rocks are folded into asymmetric anticline with an axis striking towards the northeast. (Abou el-Enin, 1966, p. 185). The northwestern limb of this dome, on which the examined area is located, dips at an angle of about 10 to 20 degrees. The south-eastern limb dips steeply, and is in parts, approaching vertically. This is a result of a major fault which throws to the southeast, bringing in Cretaceous strata on that side. The throw of this fault is estimated to be of about 800 metres. The strata, on the northwestern limb are further dissected by dip faults which throws, ranging from a few metres up to 100 metres, and to a less extent by strike faults with minor displacement [1].

II. — CHARACTERISTICS AND GEOMORPHOLOGICAL SIGNIFICANCE OF THE DRAINAGE'S SEGMENTS WITHIN THE INVESTIGATED AREA.

The Maghara District, as an integral part of North Sinai, is dominated by arid climatic conditions. The amount of mean annual rainfall in the area varies from 30 to 40 m.m., and that amount of rainfall occurs

[1] See the detailed geological maps of the area in, Abou el-Enin, H.S. (1966), Cuesta features... in the Maghara District, *Bull. Soc. Géog. d'Egypte*, t. XXXIX, pp. 173-192.

mainly during the afternoon thunderstorms of the winter season. The number of the rainy days is very few, and of about 3-6 days a year. Winter rainfall therefore, is associated with the passage of the Westerlies depressions, which in their west to east course, release some of their moisture over the upland of Gebel el-Maghara (730 metres O.D.). Under the cyclonic and thunderstorm activities rainfall in the area under consideration is typically torrential and spottiness in character. The great amount of rainfall occurs on top of Shusht el-Maghara and thus produces vigorous torrents descending on the mountainous slopes. Consequently, most of the so called «dry valleys» or «dry wadies» within the area behave, for few hours during the rainy-days, as ordinary streams. Davis (1938) recognised such streams within the western deserts of the U.S.A. and referred to them as «stream-floods», rather than «desert-streams», because of their irregular, spasmodic and impetuous flow. As soon as, the rainfall stops, such streams or wadies dry up, and become in a still-stand condition. The tributary wadies do not reach the sea [1], and flow mainly in the Masajed Basin. Within such internal drainage, the concept of sea-level as a general base-level control does not apply. Though such wadies are initiated by the work of rainfall, their alignments, and general drainage pattern are partially influenced by the structure and lithology of the underlying rocks.

It is useful to review briefly the Davision classification of surface forms, before attempting to explain to what extent the drainage segments of the Maghara District are structurally-controlled features, and the effect of the successive pluvial phases of the Pleistocene on their development. Davis, W.M. (1899, p. 249) stated that all surface forms are the product of three basic factors namely, structure, process and stage. He, further, suggested that surface forms may be divided into two major groups, which he termed initial or constructional, and sequential or destructional surface forms. The first group consists of surface forms produced directly by epeirogenic, orogenic or volcanic activities, while the second group consists of surface forms developed by gradational agents.

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[1] Except Wadi el-Arish which extends northward to the Mediterranean sea-coast of Sinai, and flows as a hanging valley nearby el-Arish.

These two broad concepts of surface form development have recently been criticised by many geomorphologists from a variety of view points. Strahler (1946 and 1950) claimed that the Davision classification of surface forms is invalid since the development of most of them is influenced by a complicated series of geomorphogenetic processes. He further considered Davis to have placed two much emphasis on the study of stage and too little on the structure and process. Others, such as Maxon and Anderson (1935, p. 88) reviewed the concept of the Davision erosion cycle and proposed a logical terminology applicable to both the humid and the arid cycles of erosion. Both Lewis, G.M., (1959, p. 26) and Russell (1949), criticised the Davision description of surface forms. The former, supported the latter in considering the Davision geomorphology to have encouraged deductive explanation rather than empirical description. The geomorphologist may concern himself deeply with questions of structure, process and stage, but the geographer wants specific information along the lines of what, where and how much.

Field investigation within the Maghara District had revealed the difficulties of producing an absolutely logical geomorphogenetic classification of the drainage's segments, since the majority of them are a result of both gradational and structural factors.

Wadies are originated by heavy rainfalls particularly during the pluvial phases of the Pleistocene. They are modified by the torrential heavy rainfall of the present day, whereas the alternating shales, sandstones, muds and limestones have influenced to a considerable extent the modification of the drainage pattern.

For the sake of simplicity four elements of drainage are distinguished namely (Fig. 1) :

a) The subsequent or the north-eastward-flowing wadies.

b) The consequent or the north-westward-flowing wadies.

c) Gullies and obsequent deeply incised vales.

d) The dry wash of the Masajed Basin.

The following is a brief account of the morphological significance of each of these elements.

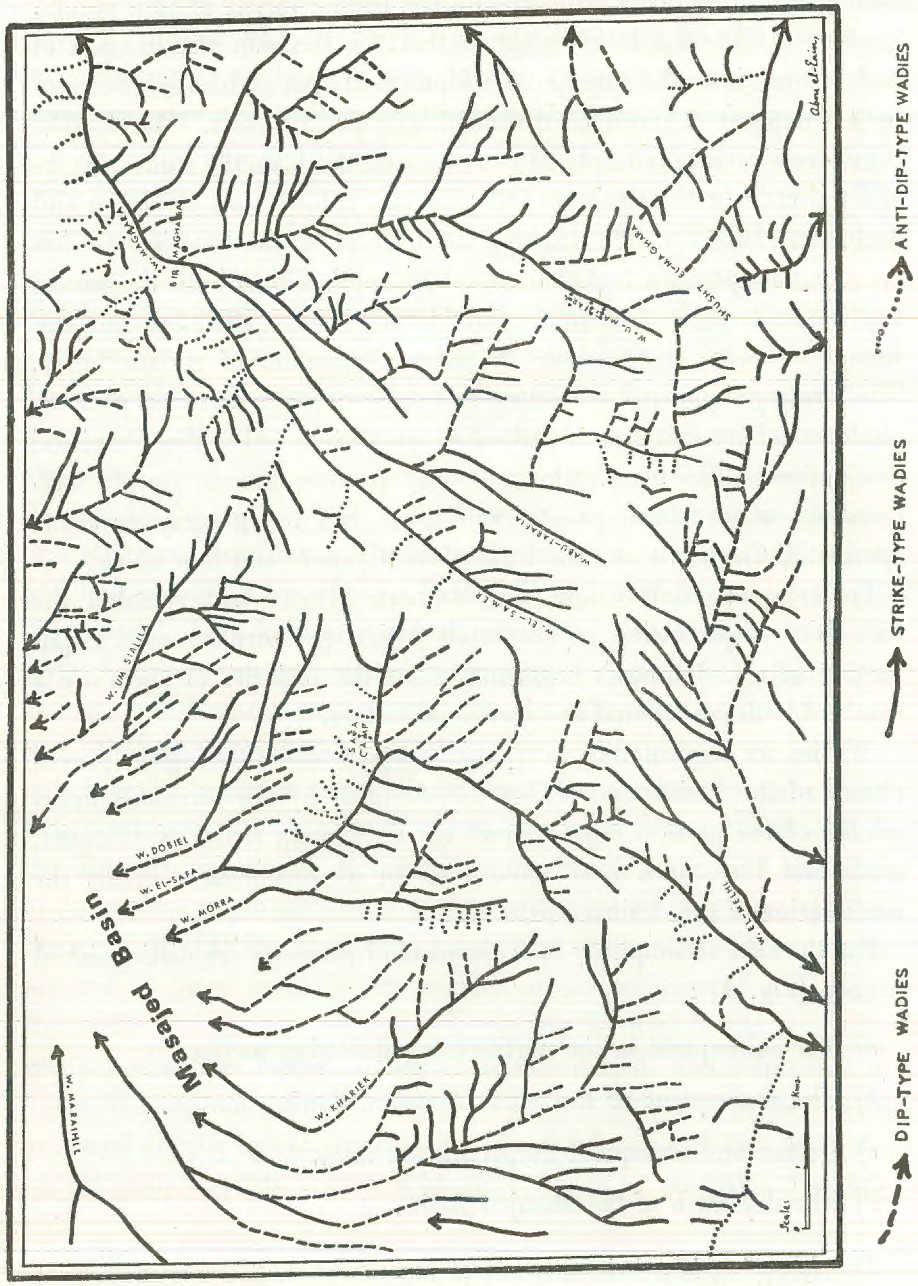

Fig. 1. — Wadies classified according to structure.

a) The subsequent or the north-eastward flowing wadies :

This group of wadies consists of the upper tributaries of Wadi el-Maghara namely, the Upper Maghara, Abu-Tarafia, and El-Samer Wadies. The upper wadies rise at about one kilometre to the west of Shusht el-Maghara at a height of about 680 m. O.D. Their heads comprise a large number of deeply incised gullies. They are generally subparallel, flowing north-eastward and are joined together near Bir Maghara in the north-eastern part of the area under investigation.

A comparison of the drainage and the geological maps reveals that the north-eastward flowing wadies cut across different rock-outcrops (particularly the Coal-Measures and the Flinty Limestone formations of the Middle Jurassic), and extend along with the Gebel el-Maghara anticlinal axis. They are therefore strike-type (subsequent) wadies, excavating their deeply incised courses along the main geological weakness in the area. The wadies cut their courses across the shale bands, and are bounded by high, steep valley sides and scarp slopes.

The wadi of Upper Maghara is surrounded by high walls (rising to about 40 metres above the valley-floor) formed of thick bands of the Flinty Limestone, while the upper courses of Wadi Abu-Tarafia and Wadi El-Samar are bounded by oolitic and sandy limestone scarps. In spite of this gorge-like incisions, narrow patches of flood plain have been observed within the floor of these upper wadies. The flood plain deposits are found to be comprised of sandstone, limestone and flinty limestone fragments mixed in a matrix of shale, clay and silt. These rock-fragments have the forms of boulders, cabbles, pebbles and coarse sands. They are heterogeneous unsorted, roughly rounded, and have sometimes sharp edges and are generally non-stratified. As a result of the lack of water within the wadies, it seems that their courses were not able to carry their loads of fragments down streams.

Field investigation and cartographic examination of the longitudinal profile of the Upper Maghara and its tributary wadies revealed that the floors of the upper wadies are characterised by a series of steps which vary between 1 to 3 metres in height, and 100 to 300 metres

apart. (Fig. 2). Due to the fact that this group of wadies are of internal drainage their headward or vertical erosions are influenced by the local or structural base-level. These «knick-points» or the rejuvenated steps are here determined by the underlying rocks, since shale bands are eroded more rapidly than the massive limestone and flinty-limestone bands.

b) THE CONSEQUENT OR THE NORTH-WESTWARD FLOWING WADIES :

This group of wadies descends on the north-western limb of the Maghara Dome, following the direction of the dip and flow into the Masajed Basin. They are referred to as consequent or dip-type wadies. They are generally subparallel, rising at the major interfluvial crests of the western side of Wadi El-Samer at heights which vary from 490-580 metres O.D. The wadies are strikingly short and are from 3 to 6 kms. in length. They include — from west to east — the Wadies of Meraihil, Khariek, Barbour, Khattar, Morra, El-Safa, Dobiel, Um-Sialila, Rahma, and Sheikh Hamid, respectively. The floor of the wadies vary from 5 to 25 metres in width, filled in many parts with silts, sands and gravels. They comprise a series of alternating steeper and gentler reaches, with rapid, and/or, fall-like-features occurring, at — or, near the heads of the steeper rejuvenated steps.

A comparison of the drainage map with the structurally controlled features and the geological maps, (Abou el-Enin, 1966, p. 186) indicates that the majority of this group of wadies are bounded by steep valley sides, and wall like scarps of major and intermediate cuestas. Though this groups of streams generally follow the direction of the dip, some parts of their upper and middle courses coincide with fault planes. The upper courses of Meraihil, Khariek, El-Safa and Um-Sialila Wadies, are generally excavated along the Meraihil, Khomashia, Safa-Um Kfar, and Sismara fault-planes, respectively.

Consequently, the north-westward flowing wadies within the area under investigation display little variation in the width of the vales, or of their valley's bottom. This may be related to :

1. The shortness of the wadies, and the scarcity of the rainfalls do not give them the power to construct wide plains or floors.

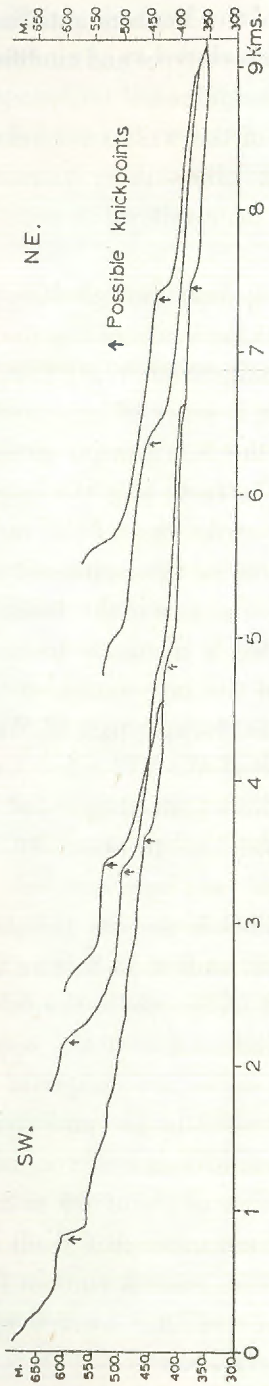

FIG. 2. — Longitudinal profile of the upper Maghara and its tributaries.

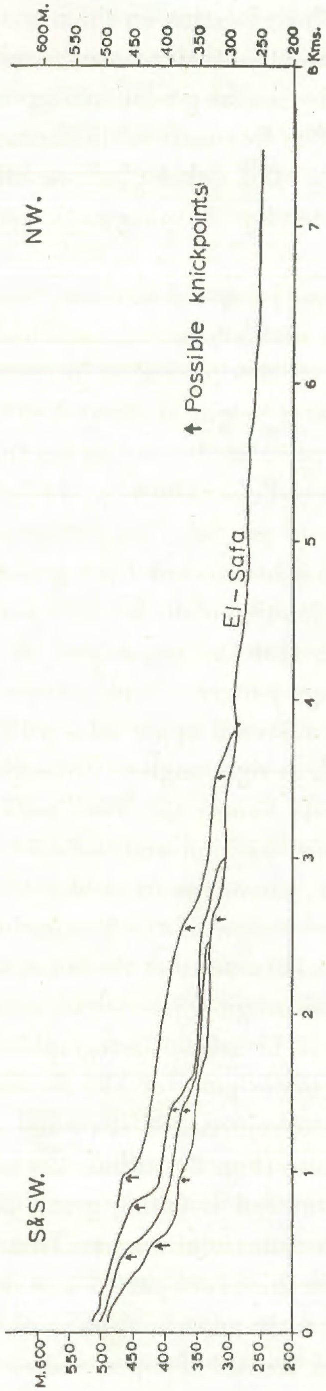

FIG. 3. — Longitudinal profile of the W. El-Safa and its tributaries.

2. Their location on the north-western limb of the Maghara anticline, and that their courses running along similar rock-types and modified by similar gradational agents under arid conditions.
3. The frequency of the successive incisions of the wadies according to the lithological variations, does not allow them time to develop morphogenetic variations within their valleys.

It may be useful however, to summarise the geomorphological significance of Wadi El-Safa, which clearly represents the series of the north westward flowing wadies in the area under investigation. Wadi El-Safa rises at a height of about 580 metres O.D., in a series of subparallel dip-type vales descending on the dip-slope of the Safa's major cuesta. (Abou el-Enin, 1966, p. 187). These vales, in turn, join the upper course of the Safa Wadi which runs across the strike line of the rocks as a north eastward flowing wadi from its source in the southwest up to the location of the Safa Camp in the northeast. The map of the drainage reveals that the upper part of Wadi El-Safa has a distinctly trellised drainage pattern. This pattern is the result of the intersection of the north westward upper vales with the north eastward upper part of Wadi El-Safa at right angles. Through the middle part of Wadi El-Safa (down the Safa Camp) the Wadi cuts its course across fault-planes and is bounded by high and wall-like valley sides which rise to about 30-50 metres, above the Wadi-floor.

Examination of the longitudinal profile of El-Safa and its tributary wadies indicates that the latter flow into the main wadi of El-Safa on the form of hanging dry-valleys, rising at about 3-8 metres above the valley floor of El-Safa. Cartographic analysis also indicates that the upper and middle parts of El-Safa and its tributary wadies are comprised of series of rejuvenated steps and are mainly controlled by the underlying structure (Fig. 3). While the lower part of Wadi El-Safa is of very faint gradient and is falling gently since it has a drop of about 40 metres over a distance of 8 kms. That, however, does not mean that Wadi El-Safa in this lower part is a completely graded wadi since it runs in this part on the superficial plain of El-Masajed Basins which is covered with a thick blanket of deposits of about 35 metres in thickness.

Due to the sparsity of vegetation, scarcity of rainfalls, and the extremely great daily and seasonal ranges of temperature, the massive sandstones exposed on the valley sides of the middle part of Wadi El-Safa are subjected to extensive exfoliation. Field investigation indicates that the thick bands of sandstones are heavily jointed and cracked. This in turn facilitates the process of rock-falling. Numerous large blocks of sandstones and boulders are usually observed on the floor of Wadi El-Safa, particularly at the foot of the wall like jointed sandstone scarps (Pl. I, A).

One kilometre to the south of El-Safa Camp, the steep valley sides of Wadi El-Safa are composed of 8 metres of extensively cracked sandstone overlain a band of shale of about 5 metres. The sandstones are widely exfoliated and talus slopes and large blocks falling from above are often found nearby the foot of the wall-like valley sides. The process of rockfall, therefore, and scarp recession are responsible in some way for the successive widening of the valley floor of Wadi El-Safa (Pl. I, B).

Unlike the upper and middle parts of Wadi El-Safa, its lower part (three kms. down the location of the Safa Camp), is of a comparatively gentle gradient. The lower portion of Wadi El-Safa, is partially filled with flood plain deposits and is in many parts deeply alluviated. In the area of the Safa Camp, the Safa valley sides are totally comprised of thick walls of 10 metres of alluvial deposits (Pl. II, A-B).

Examination of the alluvial deposits within the valley sides of Wadi El-Safa indicates that they are formed of cobbles, pebbles and gravels mixed in silty-shale matrix. These rock-fragments are found to be non-homogeneous and carried from the upper part of the Wadi during the flood conditions. The rock-fragments are also of sharp edges and, are generally scattered in the silt matrix. It has been observed, however, that the rock-fragments are roughly arranged in the form of subparallel bands-like separated by shale and silt. This, in turn, may explain the variations in the flood conditions within such wadies.

The writer suggests that in such flattish areas within the lower parts of the wadies, the muddy water running in their bottoms, immediately after each torrential rainfall, spreads out in a broad sheet of shales and silts and sweeps rapidly across the surface. Running water at the same time usually carries with it the sands and rock-fragments brought down

from the upper part of the valley to be deposited wherever the water chances to leave them.

Dip-type wadies within the area under consideration are, therefore, not completely adjusted to structure. Though some wadies have succeeded to excavate their courses along the geological weakness in the area as fault planes and the soft and weaker beds, yet all of them are in a still stand condition. In other words the processes responsible for their initiation are not working at the same rate at the present time.

c) GULLIES AND OBSEQUENT DEEPLY INCISED VALES :

This group of vales represents a series of very short wadies running across the very steep scarp's slopes, each of which varies from 400-800 metres in length. They are, therefore obsequent or anti-dip-type vales. They are modified by the heavy torrential rainfall which usually takes place in the area under consideration at least twice a year. Since they flow into the major nearby strike wadies as hanging valleys, their courses are deeply incised during the occurrence of the torrential rainfalls. By the aid of their heavy loads which are usually comprised of coarse fragments, boulders and sands, descending with the water from the upper parts of the gullies into their lower ones, the wadies intermittently deepen their courses. As a result of their successive headward extensions, they acquire the form of anti-dip-type gullies cutting the scarp slopes and are usually separated by small cone-like features, and/or, small, pyramid-like spurs. Their intersections with the major nearby strike wadies are usually at right angles, forming, in turn, a distinguished trellised drainage pattern which is always associated with such scarp's and cuesta's landscape. Subsequent headward erosions by this anti-dip-type gullies are responsible for the process of scarp recession, which in turn, brings about the destruction of dip slopes at their upper ends and leads to their extension at their lower ends.

The most striking examples of anti-dip-type vales in the area under consideration are those descending on the scarp slopes of both the Sheikh Hamid and Dobiel major cuestas. (Abou el-Enin, 1966, p. 186). Within the former anti-dip-type vales rise nearby the crest of the Sheikh Hamid Cuesta and flow in deeply incised gullies cutting their courses across the scarp-slope.

Great amount of rock-debris are removed from the upper parts of the Sheikh Hamid Scarp by the work of the gullies added by gravity. This, in turn, facilitate the formation of talus slopes, which characterised, the scarp-slope of the Sheikh Hamid Cuesta.

The eastern part of the scarp-slope of El-Dobiel Cuesta is extensively dissected by anti-dip type vales than its western part (PL. III, A). In other words the scarp recession in this locality is of an unequal rate. This may be due to the fact that scarp-forming rocks in the area under consideration vary laterally in lithology and have been subjected to several morphogenetic processes operating under different types of climates (pluvial and arid conditions), and which were in turn, more active in one place, on the scarp slope than in others. (Abou el-Enin, 1966, p. 191).

Field investigation indicates that the upper parts of El-Dobiel cuesta are extensively exposed to both the effect of exfoliation and dissection by headward erosion of anti-dip-type gullies. Consequently, the upper segments of the scarps retreat faster than the lower ones, since the latter is the obvious zone of accumulation of debris and gully deposits creeping from above. (Abou el-Enin, 1973).

d) THE DRY WASH OF THE MASAJED BASIN :

The Masajed Basin is a dry wash that lies at the north-western part of the area under consideration. It is a semicircular basin having a diameter of about six kms. It is bounded in the north by a series of cresentic sand dunes, while dry wadies cut its hilly eastern, western and southern sides and flow into its central part. Its hilly marginal areas occur at a height which varies between 300 to 350 metres, while the flattish floor of its central part stands at a height of about 250 metres. Consequently, it has a distinct gradient of about 1 : 35 descending from its margins towards its centre.

Before reviewing the evolution of the drainage pattern within the area under investigation, it is useful to summarise the morphographic and morphogenetic characteristics of the southern part of this basin (Fig. 4).

It is useful in this respect to refer to the dry wash of the Masajed Basin as a bolson-like feature since it is formed of a flat plain, covered by alluvial deposits and rimmed by hills and mountains. Though the drainage pattern within the Masajed Basin is centripetal in character, there is no a moist playa, at/or, near its centre.

Three striking features may be distinguished within the Masajed Basin, namely :

1. The pediment-like slopes.

2. The bajada slopes.

3. The broad alluvial fans.

The pediment-like slopes occupy the outer fringing area of the Masajed Basin and represent a transitional zone between the mountainous flanks of the Maghara Dome, and the flattish floor of the Masajed Basin. They are eroded rock surfaces, in parts, thinly veneered with fluvial gravels, lying at the foot of the hills and mountains which surround the Masajed Basin from all directions except from the north. They have gentle slopes produced by the backward recession of the mountainous side of the Maghara Dome. Their slopes generally vary from 1 to 8 degrees, but they are more steeper (more than 15 degrees), at their upper parts where they intersect with the mountainous slopes. Consequently, a sharp break of slope is usually observed where a pediment-like slope meets a mountain front (Pl. III, B).

While the upper parts of the pediment-like slopes within the area under consideration are generally conoplains, their lower ends which descend towards the floor of the Masajed Basin are formed of outwash detrital slopes, and may be referred to as bahada or bajada surfaces. In other words, the pediment-like slopes are zones of erosion and aggradation but the bajada surfaces are zones of deposition, and accumulation. Materials of the bajada surfaces within the area under consideration generally consists of gravelly alluvium, but large sandstone and limestone boulders are sometimes interbedded with mud flow and sheet-wash deposits. (Abou el-Enin, 1973).

Field investigation has also revealed that the short dry vales and gullies cutting across the bajada slopes and descending towards the floor of the Masajed Basin give rise to small and pyramid-like alluvial cones. The latters are well observed on the bajada slopes near the mouthes of Wadies Um-Sialila, Dobiel, El-Safa, and Meraihil (Fig. 4). Alluvial cones are found to be variable in size and shape, since they are influenced by the configuration of initial surface-floors receiving the detritus, the amount of materials accumulated by the sheet washes, and the size and forms of the rock-fragments. However, all the alluvial cones on the bajada slopes are roughly triangular or pyramid-like in shape, and the apex of the triangle stands usually at the pediment-like slope. The writer suggests that alluvial cones within the area under consideration are formed where sudden rushes of water from torrential rains emerge from the wadies, then suddenly lose their velocity, and deposit their loads of detrital material in the form of cones at the fringe of the Masajed Basin.

On the other hand, field investigation indicates the formation of large and broad fans with very gentle gradients, existing at the final ends of the large wadies where the latter disappeared gradually, on the floor of the Masajed Basin.

The lower ends of the Meraihil and El-Dobiel Wadies are distinguished by a most striking set of broad fans (Fig. 4). Field examination of the broad Meraihil fan indicates that it has a gentle slope descending from its rear towards its toe or front, and is of about 1 to 3 degrees. The fan generally consists of fragmentary material foreign to the underlying rock of the floor of the Masajed Basin. The rock-fragments are carried down from rock exposure at the crest and on the western limb of the Maghara Dome by the successive work of Wadi El-Meraihil, sheet-wash and occasional mudflows. It is found that coarser rock-fragments are associated with the upper parts of the Meraihil fan, while the finest ones are farthest from its apex (Pl. IV, A-B).

Debris deposition on the Meraihil fan is in the form of a long, relatively narrow strip of material extending radially from the apex to near its margin. Debris and mud flows which occurred during the last few years, occupy the middle part of the fan. While older deposits, whicb are

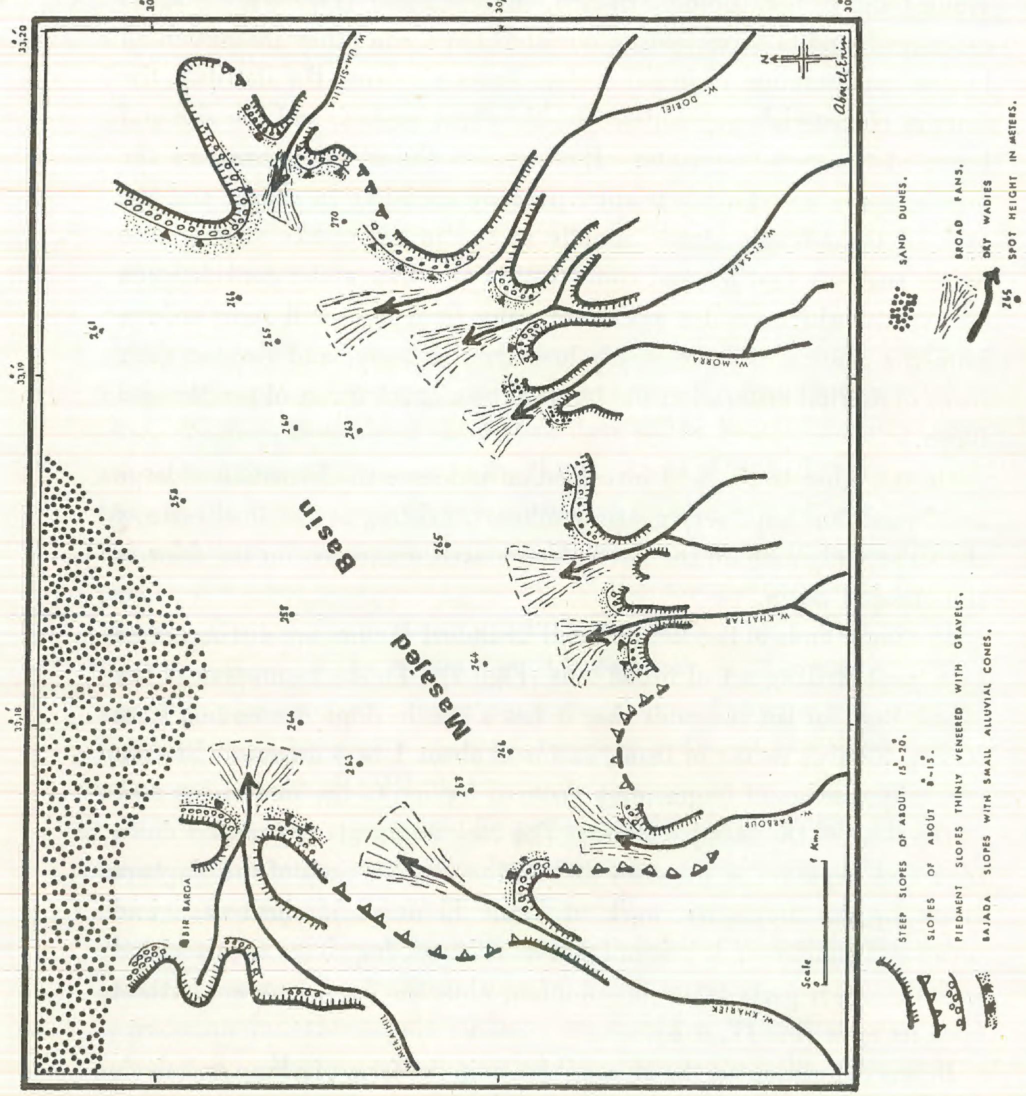

Fig. 4. — The Morphology of the Masajed Basin.

dissected by older channels reside on the western and eastern wings of the fan (Fig. 5). Field investigation has also revealed that the older hannels on one side of the fan are subparallel flowing channels, while on the other side they are of braided drainage. The average depth of the channels is found to be of about 1 to 2 metres.

Excluding the marginal boundaries and the broad fan areas of the Masajed Basin, its remainder area exhibits little relief. The middle part of the Masajed Basin is a flat almost smooth surface broken only here and there by small depressions and gentle rises. It has a gradient of about one degree and the surface is made up largely of sand and gravel. Mixed with the sand and on the surface are numerous pebbles, cobbles and few boulders. The larger rock-fragments show the effects of water transportation and are angular to subangular in shape. The alluvial deposits which have covered the floor of the Masajed Basin are estimated to be of about 30 metres in thickness.

Consequently, we can safely say that the drainage pattern over the Maghara Dome is radial in character, since the wadies radiated from the top of Shusht El-Maghara in all directions towards the lowland areas. But on the western side of the dome the drainage elements have partially been influenced by the underlying structure. This gave rise to the trellised drainage pattern which distinguishes the valleys of the Safa, Khariek and Um-Sialila. However, the drainage pattern in parts can be considered, as centripetal in character since the dry wadies in the area under consideration flow from all directions towards the central part of the Masajed Basin.

III. — EVOLUTION OF THE DRAINAGE PATTERN.

In any attempt to elucidate earlier stages of the drainage pattern, it is essential to work as Brown (1960, p. 125) suggested, from the known to the unknown. In other words, it is useful to follow the Huttonian doctrine of uniformitarianism and to work according to his famous concept : «the present is the key to the past». Consequently, after we have first discussed the characteristic of the drainage segments and the relationship between the present wadies pattern to the underlying

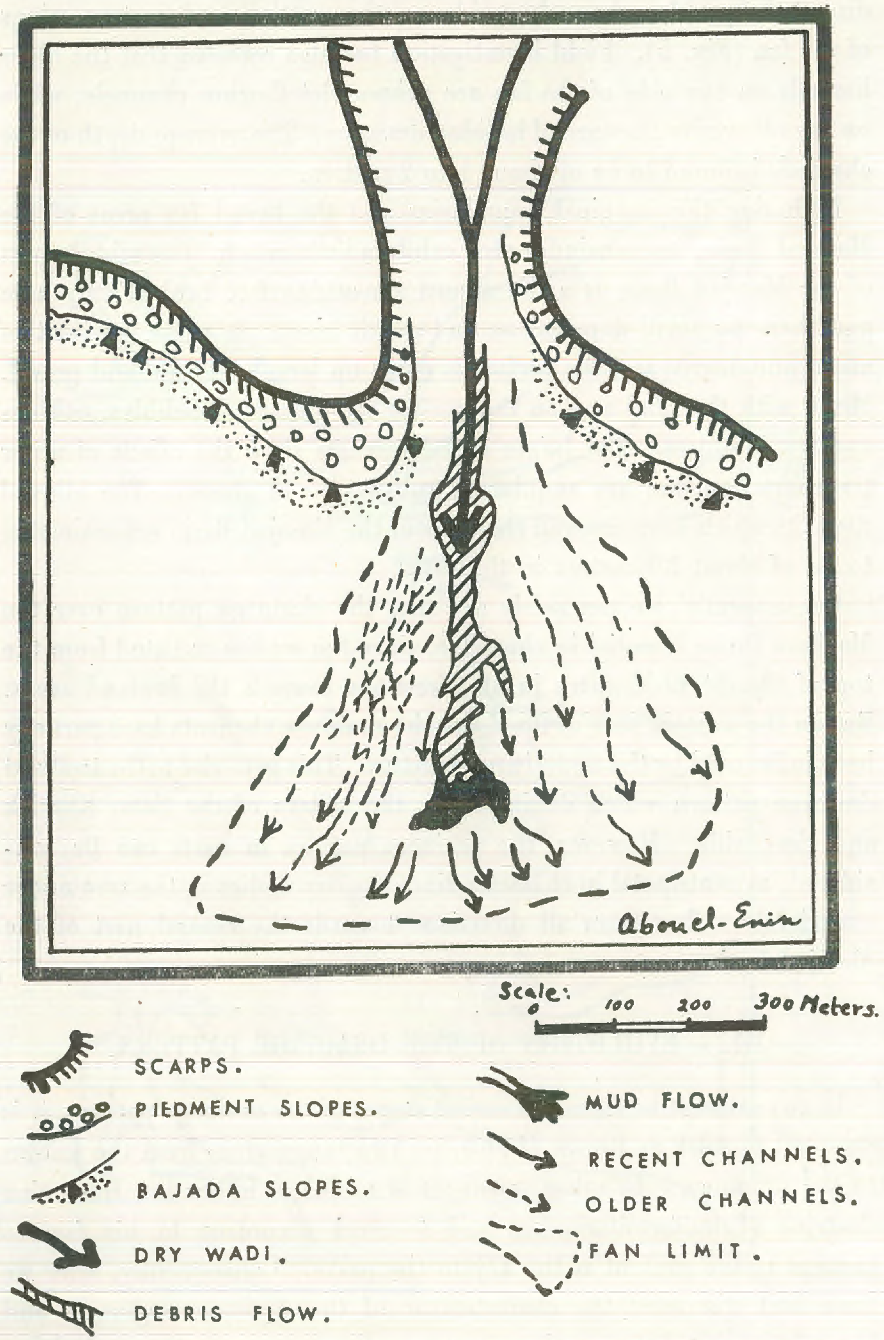

FIG. 5. — The Morphology of the Meraihil fan.

geological structure, it is convenient to refer here, to the evolution of the drainage pattern, and to offer a proposal, concerned with the initial main streams within the area under consideration.

The drainage pattern within the Maghara District may be regarded as the latest stage in the modification of an initial system ever since the time of its initiation. The present drainage pattern, therefore, may carry the imprint of most of the events which have produced it.

Field investigation has revealed the existence of three groups of «surface flats» (1), occurring at different heights within the area under consideration (Fig. 6). These relics can be referred to as :

a) The Shusht El-Maghara Stage (615-720 metres, O.D.).
b) The Safa Stage (520-610 metres, O.D.).
c) The Khariek Stage (410-470 metres, O.D.).

Though, the wadies in the area under consideration are in a still-stand condition, and excavate their valleys with regard to the structural or local base-level, yet the flats observed on the major watersheds are of subaerial origin. They are thought to be erosion surface remnants since they are not determined by the underlying structure. These remnants are not geometrically flat, but they commonly consist of very faint and gentle slopes descending towards their frontal edges. They are developed on various types of rocks and have mainly preserved on the primary and secondary watershed areas and on the crests of the bevelled cuestas.

Erosion surface remnants related to the Shusht El-Maghara Stage are mainly preserved on sandstones and limestones of the Coal-Measure

(1) Sparks, (1949, p. 167) has used the term «flat» to refer to an individual relic of an erosion surface, and has noted that the flat visibly posses a lower degree of slope than its surroundings. Humphries (1958 p. 37) has used synonymously the term «surface flats» for the large erosion remnants, while the term «valley benches» was restricted to narrow facets, usually found along the sides of river valleys. Wooldridge (1950 p. 164) pointed out that the term «erosion surface» or «erosion platform», is graphic and self-explanatory and in some cases apt enough, yet the purist may insist that a platform should be flat or nearly so. Since the erosion flats are not completely flat, the writer prefers (1964 a, b and in 1973) the term «erosion surface remnants» to refer to them.

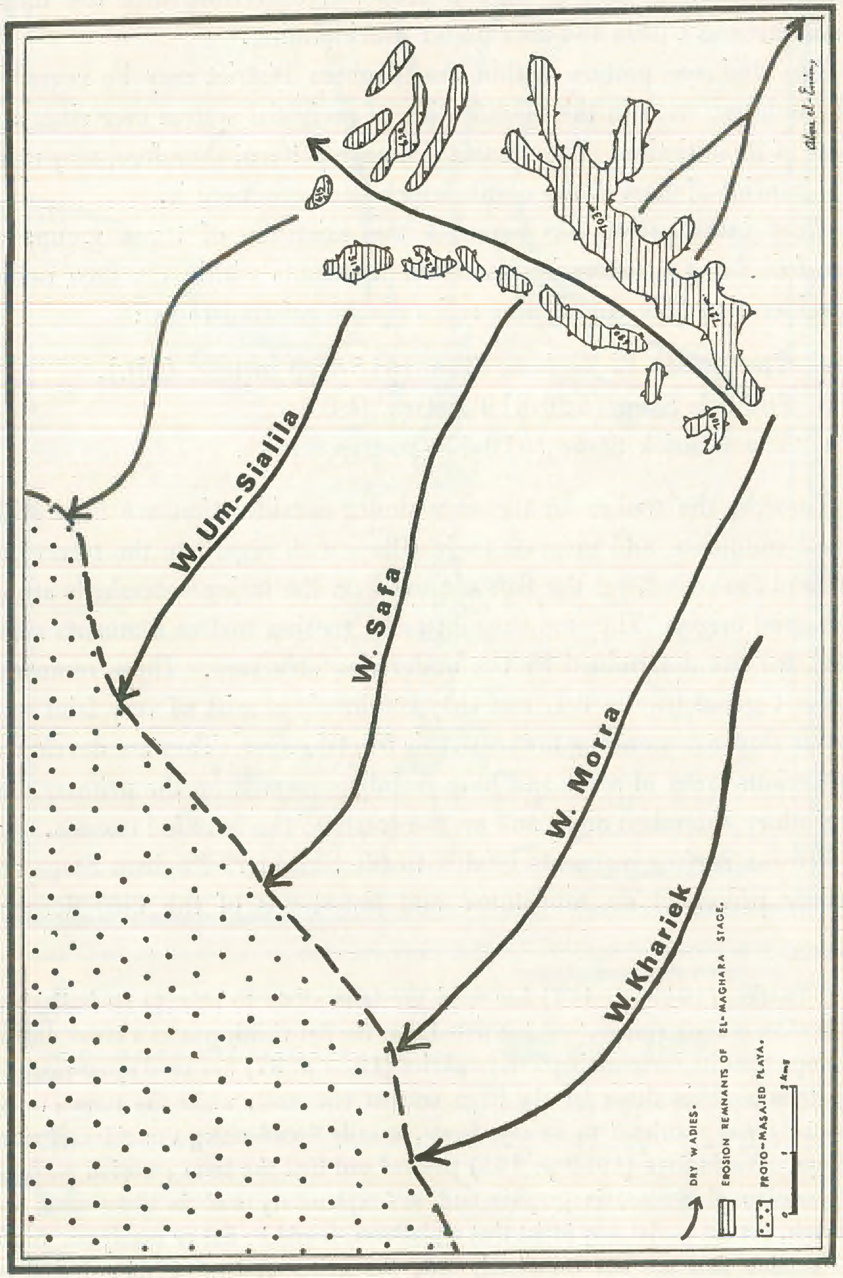

Fig. 6. — Drainage pattern during Shusht El-Maghara Stage.

series and have in parts developed on the Flinty Limestone of the Bathonian Stage. They occur on the highest interfluvial areas between the upper reaches of the Upper Maghara Wadi, and the upper gullies descending on the south-western limb of the Maghara Dome. Here the relief is very faint and slopes are very gentle although the remnants vary in height from 615-720 mertes, O.D.

Erosion surface remnants related to the Safa Stage are developed on the secondary watersheds, and on the gentle slopes of the bevelled cuestas in the area under consideration. They occur at heights which vary between 520-610 metres O.D. They have preserved on the resistant members of the Callovian formation (i.e. sandstones, limestones and chalky limestones). The widest remnant is that observed on the crest of the Safa Cuesta (Fig. 7).

Erosion surface remnants of the Khariek Stage are mainly developed on the secondary watersheds of Wadi El-Samer and Wadi Abu-Tarafia. They have poorly developed into small relics on the gentle slopes of the small-sized and bevelled cuestas in the north-western part of the area under consideration. They vary in height from 410-470 metres O.D., and have generally preserved on the Chalky Limestone series. They are best observed on the watersheds of Wadi El-Khariek (Fig. 8).

Though the surface remnants observed in the field are not structurally controlled, and though the writer does try to pay more attention in definition, recognition, and delimitation of these remnants, yet the chief problem is concerned with their origin. Cotton (1952, p. 255) has pointed out that the general base-level in arid region (as in the area under consideration) has not the importance that it has in the normal cycle as a controlling level towards which humid landscapes are lowered. He also has noted that the most important difference between arid and humid (normal) erosion among mountains is the way in which mountains are «worn back» rather than «worn down». Consequently, under the influence of continual mechanical weathering of bare rock surfaces, «pediplains» are well developed. King (1950) has widely applied the concept of pediplanation (as a result of scarp-recession) to the African plateaus and has distinguished a number of cycles of pediplanation in the time between the Jurassic period and the present day. Peel on the

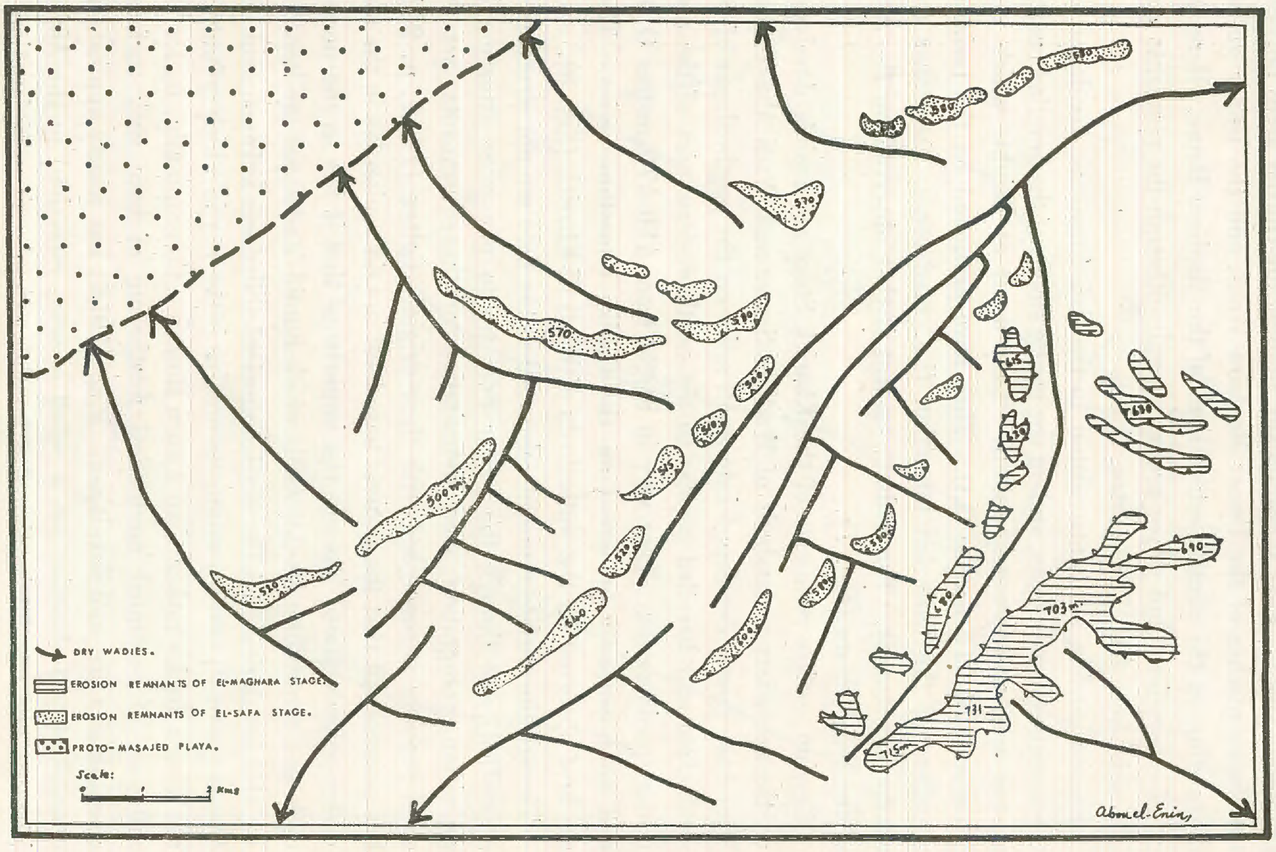

Fig. 7. — Drainage pattern during El-Safa Stage.

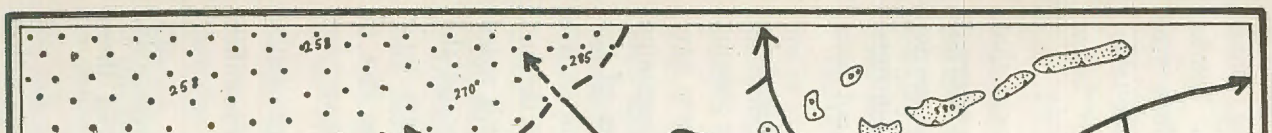

Fig. 8. — Drainage pattern during El-Khariek Stage.

other hand (1941), has noted that the flat plains surrounding the Gilf Kebir plateau in the Libyan Desert, appear to possess no trace of pediments. He suggested further that the work of spring sapping during the times of heavy rainfall may be responsible for their origin. Sparks (1960, p. 262) has pointed out that deflation in arid regions may produce hollows, the depth of which will be limited by the water-table, and which slowly expand, producing a second plateau surface below the first.

In the area under consideration field investigation has proved that the erosion surface remnants are not pediments. They are preserved on the major interfluvial crests and on the bevelled cuestas, and are not found at the foot of the scarps. Even inselbergs and the associated inclined slopes descending from their rears towards the lowland have not been observed in the area.

The writer also explains that the work of deflation (suggested by Sparks and perhaps he means abrasion), and the effect of spring sapping (suggested by Peel) cannot be applied in this area. Wind caves have not been seen in the area, and it is difficult to accept the assumption that spring sapping during former and/or the pluvial phases of the Pleistocene has the power of producing three groups of erosion surface remnants. Besides, the erosion surface remnants do not occur at the foot of scarp slopes where spring sapping may be vigorous, but as it is noted above they are developed on the major interfluvial crests. Though the erosion surface remnants in the area under consideration, have their general gradient in accordance with the major wadies, yet the idea of their origination due to the work of streams faces various obstacles such as:

1. The difficulty of observing segments of proto-vales on the erosion surface remnants, since their surfaces have been extensively modified by wind action and exfoliation.
2. Alluvial deposits are not represented on the erosion remnants, except accumulation of alluvial debris observed here and there within the bottom of some wadies.
3. Valley benches, or in other words, erosion surface remnants within the valley sides are not developed.

4. The present wadies are strikingly short in length.
5. The altitudes at which the remnants occur are of no great use, since they are not related to the general base-level.
6. The wadies are generally dry at the present stage, and are in still-stand conditions. It is also difficult to deduce the amount of vertical and lateral erosion caused by the «streams» during the pluvial conditions.

However, the writer suggests that the erosion surface remnants in the area under consideration are likely to be relics of Proto-stream erosion working to the local base-level. It is impossible therefore to correlate these erosion surface remnants with others in similar or adjacent areas.

The problems associated with the age and origin of the erosion surfaces are in turn, some of the main difficulties in establishing the denudation chronology of the area under consideration. However, relative age and possible stages in the drainage evolution may be proposed. The drainage pattern is certainly the result of several successive stages. The area had been uplifted during the Miocene and the older erosion surface; the Shusht El-Maghara surface, could be related to the end of the Tertiary time. The younger surfaces have been produced during the beginning of the Pleistocene. The writer therefore, ventures in introducing a proposal for the subsequent stages in the evolution of the drainage pattern.

The highest and oldest surface of Shusht El-Maghara has developed after the uplifting of the Maghara Dome during the Miocene. With regard to the extent, morphological characteristics and distribution of the erosion surface remnants an attempt has been made to decide which elements of drainage may be considered to have been in existence during the development of the Shusht El-Maghara Stage. It is thought that the major subparallel north-westward flowing vales (i.e. Proto-Khariek, Morra, Safa and Um-Sialila) developed on the western limb of the Maghara Dome as dip-type (consequent) streams.(Fig. 6). The Proto-Upper Maghara wadi was struggling to excavate its course along the axis of the Maghara Anticline.

During the second stage, series of strike-type (subsequent) streams developed and, deeply incised their valleys across the geological weakness.

Consequently, the upper reaches of the consequent subparallel north-westward flowing streams were captured by the strike streams of Wadi El-Samer and Wadi Abu Tarafia. While the Wadi of the Upper Maghara was strongly developed coinciding with the axis of the Maghara Dome. Erosion remnants of the Safa Stage are perhaps related to this stage (Fig. 7).

The third stage, which was perhaps responsible for the formation of the Khariek erosion surface, developed under the extensive work of stream erosion during the pluvial conditions of the Pleistocene. Subsequent modification of the strike-type streams and the formation of the erosion remnants on the bevelled cuestas could be related to this stage. The writer suggests that the consequent subparallel north-westward flowing streams in the area under consideration flow into the Proto-playa of the Masajed Basin. Due to the present aridity of the area, the powerful action of evaporation, and the great amount of debris produced by the wadies, the Proto-playa has been dried up and took at present, the form of a flat-floored bottom of a dry wash or a bolson-like feature (Fig. 8).

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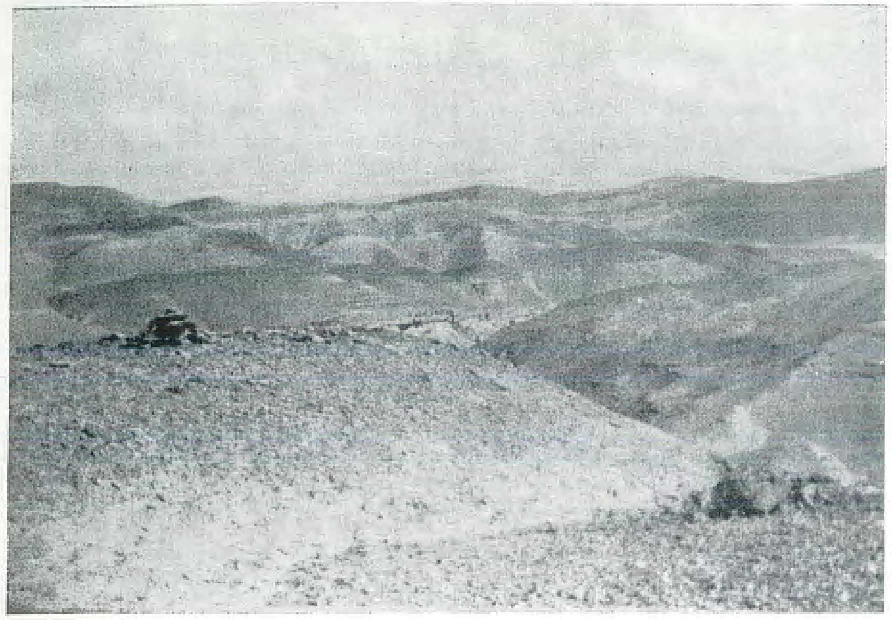
A. — Exfoliated and jointed rocks on the eastern valley-side of El-Safa Wadi.

B. — A cracked and heavily jointed valley-side of El-Safa Wadi.
Note : a) The extensively cracked sandstones which overlain a shale band. — *b*) The occurrence of rock-falls. — *c*) The widening of the valley floor by scarp recession.

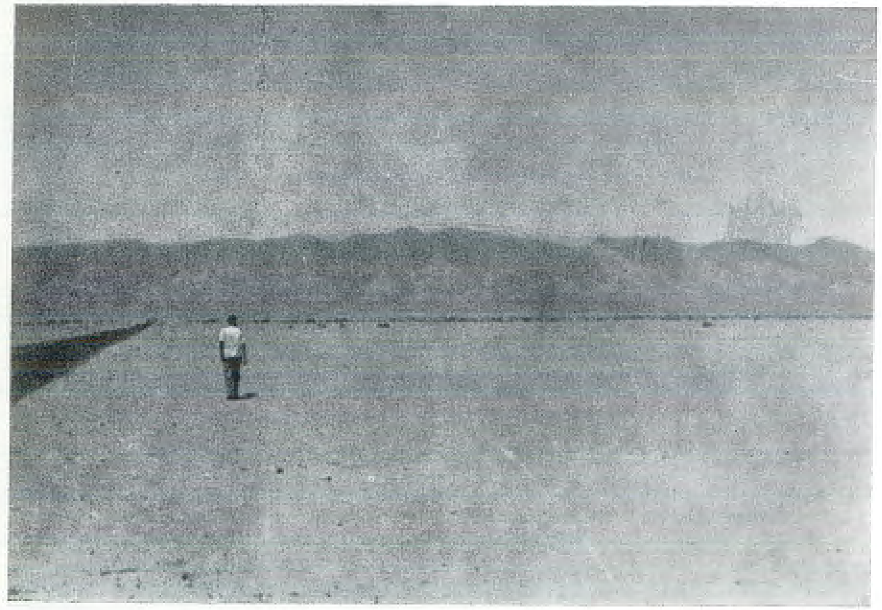
A. — A thick wall of alluvial deposits on the western valley side of El-Safa Wadi to the north of the Safa Camp.

B. — A closer view of the alluvial deposits within the western valley side of Wadi El-Safa.

Note : The rock fragments which are mixed in silt and shale matrix are of sharp edges and roughly arranged in the form of subparalled bands-like separated by shale and silt.



A. — Anti-dip type vales cutting the scarp-slope of El-Dobiel Cuesta.



B. — A general view of the flattish floor of El-Masajed Basin, which is surrounded by hills and mountains.
Note : The occurrence of alluvial cones on the bajada slopes.

A. — The lower end of a broad fan at the mouth of El-Meraihil Wadi.
Note : a) The very gentle slope descending from the rear of the fan towards ist toe.
b) The differences in surface's colour of the Masajed Basin are due to the lithological and mineralogical variations of the superficial deposits.

B. — Deposits of recent mud flows occupy the lower middle part of El-Meraihil fan. The silty-clay deposits are distinguished by the growth of desert vegetation.

STRUCTURES OF BARCHAN DUNES AT THE KHARGA OASES DEPRESSION, THE WESTERN DESERT, EGYPT

(AND A COMPARISON WITH STRUCTURES OF TWO AEOLIAN MICROFORMS FROM SAUDI ARABIA)

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ABSTRACT

The type and scale of sedimentary structures in two barchans, varying in size and stage of development, at the Kharga Oases Depression, the Western Desert, Egypt, were determined by examination of vertical sections on walls of trenches cut along the longitudinal axis of the dunes.

Analysis of the structures of the two dunes revealed two major structures separated by a nearly horizontal bounding surfaces in both of them : 1 — a dipping structure composed of cross-strata, which dip downwind at high angles (29°-34°), and form the lower part of the barchans, 2 — a low dipping to horizontal structure, composed of sets of cross-strata, which dip upwind and form the upper part of the dunes.

Distinctive structural features that are characteristic of each dune are :

1. An ill-defined structure, with no clear stratification, forms the core of Dune No. 1 (the smaller and younger barchan).
2. There are two micro-structures (trough and reversed dipping beds) in Dune No. 2.
3. The angles of the dipping structure of Dune No. 1 decrease upwind from 34° to 18°.
4. The angles of the dipping structure of Dune No. 2 are consistent in all the dune body.

All the three types of cross-stratification, as described by McKee and Weir (1953), are represented in the two barchans, but the simple and plannar types are the most common, while the wedge-shaped type is the least common.

Analysis of the structural features of the two dunes suggests that they represent one form of desert dunes, i.e. barchans, but at two different stages of development which are : Late Youth for Dune No. 1, and Mid-Maturity for Dune No. 2.

A brief comparison is made between the structures of the two barchans at Kharga, and those of two aeolian micro-forms (a small stable dune and a granule ripple) in Saudi Arabia. The granule ripple, like the barchans, formed by one effective wind direction, and developed a dipping-downwind-structure. The stable dune formed by winds from two directions, and developed several sets of laminae dipping in opposite directions.

1. INTRODUCTION.

The Kharga Oases Depression is one of the seven great depressions of the Western Desert of Egypt (Fig. 1). It lies in the southern part of the Desert, 150 km. west of the Nile Valley. It extends roughly between Latitudes 24° and 26° N., and Longitudes 29° 50′ and 30° 55′ E.

The barchan dunes (which are the main type of aeolian forms in the Depression) are organised in three longitudinal belts (Fig. 2). They run in — more or less — parallel belts with the longitudinal axis of the Depression.

2. NATURE AND PURPOSES OF STUDY.

The current study represents the first phase of a long term investigation of the sand dunes of the Kharga and Dakhla Depressions, sponsored by the Department of Geography, Ain Shams University. This first phase has involved the plotting, recording and analysis of internal structure in the principal type of dunes (barchan) in the area. Two dunes, varying in size and stage of development, were chosen from the dune belt which runs east of Gabal El-Ter and Gabal Tarawan at a locality lying 1.0 km. SW of Gabal Tarawan, to determine the main types of stratification and

cross-stratification in each of them. Also included in the study an attempt to learn what structural features are common to the two dunes and what are distinctive of each of them.

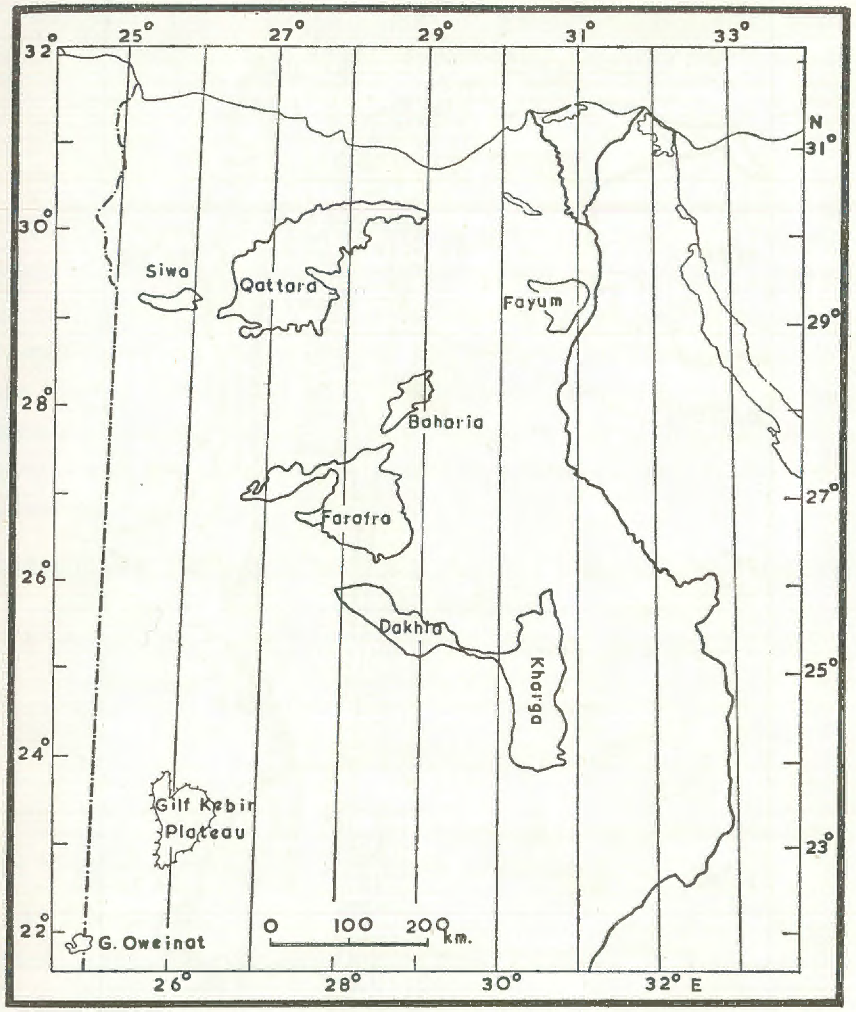

Fig. 1. — Location of the Kharga Depression.

A second phase of the investigation to be reported later includes gross measurement of dune movement determined by recording distances with respect to fixed stacks at definite time intervals.

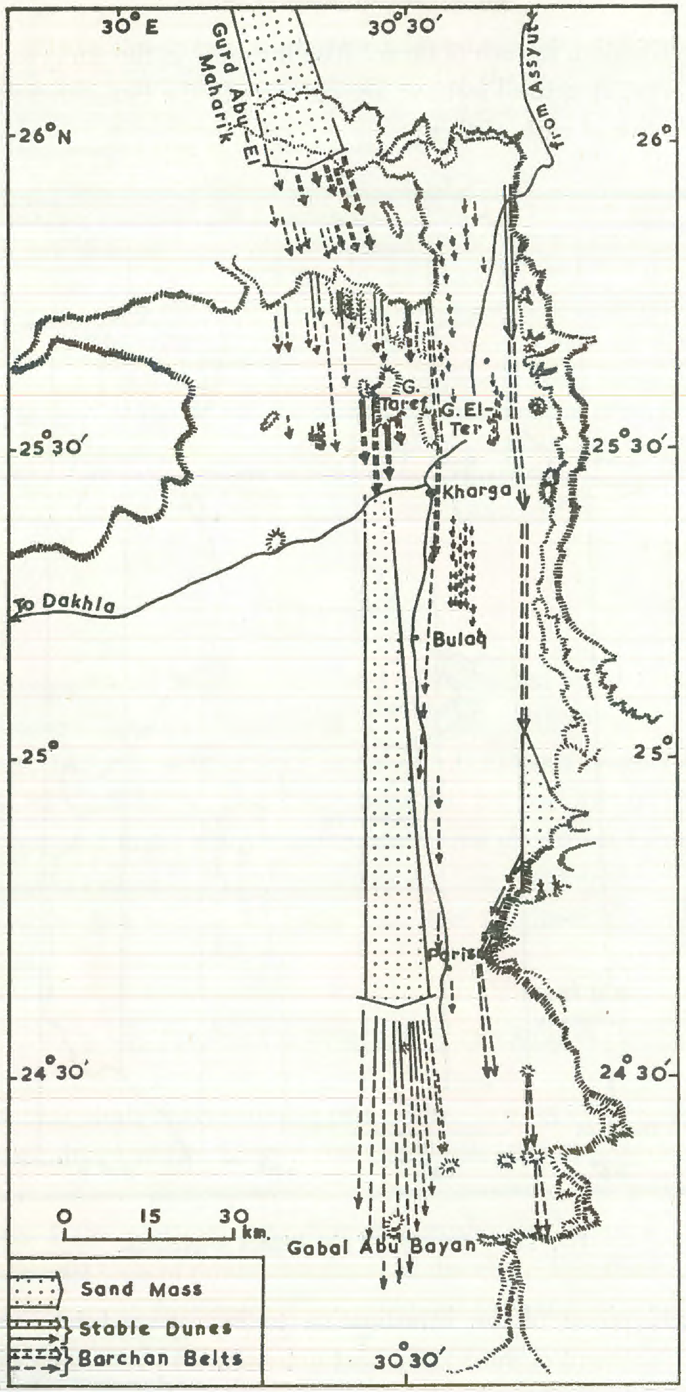

FIG. 2. — Distribution of Sand Dunes in the Kharga Depression.

A third phase of the investigation is a study of the cycle of development of barchans. Former studies and field observations of the author (Embabi, 1967) indicated that the barchan is almost the only living landform in deserts.

The fourth phase of the investigation is concerned with other aeolian forms like stable dunes, wind ripples, and sand sheets in the two Depressions.

3. METHOD OF STUDY.

The structures described in this paper were exposed by digging a series of trenches along the longitudinal axis of the two dunes, parallel to prevailing wind direction (PL. II). Since the dune sand is friable, the trenches were cut after water was poured slowly on dune surfaces along the lines of trenches, to make some cohesion in sand grains. As these trenches were dug, their sides were trimmed smooth to eliminate artificial gouges and grooves and to emphasize stratification. Details of internal structure were — then — recorded in two ways :

1-A complete coverage to scale was prepared using an abney level and linen tape to measure dips and thickness of laminae.

2-A photographic record was made to illustrate principal features of stratification.

4. TERMINOLOGY.

The principal terms used in this paper are those in common use in the literature and need be only briefly mentioned here. They are :

1. Barchan dune : a dune of crescentic form; horns of the crescent extend downwind. In many areas (Peru, California, S. Tunis, Dakhla Depression), as in Kharga, barchans are organised in longitudinal belts and are separated from one another on flat surfaces (Finkel, 1959; Coque, 1962; Long and Sharp, 1964), while in other areas, as in the White sands dune field, New Mexico, U.S.A., they tend to coalesce and fuse to form complex masses (McKee, 1966, p. 9).

2. Crest or summit : highest point on a dune.

3. Windward slope : surface sloping gently to windward, up which sand moves by saltation or creep.

4. Slip-face : surface sloping steeply to leeward (at or near angle of repose), down which sand slides or on which it settles from suspension.

5. Stable dune : a tail-like sand ridge which develops in the lee of fixed obstacles.

6. Granule ripple : a large wind ripple formed partially of granule grains.

7. Effective wind : wind having sufficient force to move appreciable amounts of sand.

5. WIND CONDITIONS.

Table 1, summarises surface wind conditions at Kharga meteorological station, which is adjacent to the Dune Belt. The table clearly indicates that :

1. Winds from all directions are represented.
2. Most of the winds are too weak to have much significance in the development of dunes.
3. The northerly winds are the prevailing ones.
4. Nearly all effective winds, i.e. velocities greater than 20 km./hr., are from the north, and this is in accordance with the orientation of dune belts in Kharga.
5. For a short period, moderate winds (20-49 km./hr.) from westerly direction, and strong winds (50-88 km./hr.) from southerly directions are effective, as will be shown later in the paper.

Thus, the dunes of Kharga may described as being under dominantly wind control from the north, but subject to a brief shift in wind direction from the south and west.

6. CHARACTER OF SAND.

Dune sand in Kharga Depression is virtually all quartz. The grains are, therefore, sufficiently hard not to be readily affected by forces of mechanical erosion and not to be changed rapidly in size and shape.

TABLE 1

Wind conditions in Kharga Meteorological Station, 1966-1970.

Unrecorded	Calm	Variable	Wind speed	Northerly 315°-44°		Easterly 45°-134°		Southerly 135°-224°		Westerly 225°-314°		All Directions	
Days	Days	Days	Km./hr.	Days	%	Days	%	Days	%	Days	%	Days	%
			I- 1-19 km.	167.04	72.0	16.58	7.1	10.48	4.5	37.90	16.4	232.00	100
9.73	2.00	3.4	II-20-49 km.	111.23	94.4	0.19	0.2	0.50	0.4	5.83	5.0	117.75	100
			III-50-88 km.	0.10	83.9	0.00	0.0	0.02	16.1	0.00	0.0	0.12	100
			All speeds	278.37	79.6	16.77	4.8	11.00	3.1	43.73	12.5	349.87	100

Computed from the monthly weather reports of 1966-1970, published by the Meteorological Department of Egypt.

Sand grains within the barchan dunes of Kharga range mostly from subangular to subrounded (Embabi, 1967, p. 245). The four samples which were taken from the crest and toe of the two dunes are dominantly within the medium and fine grade size range (Table 2).

7. PREVIOUS WORK ON DUNE STRUCTURES.

Published work on dune structures is scanty. There are three papers only on structures of dunes (McKee and Tibbitts, 1964 ; McKee, 1966 ; Merk, 1960). Nevertheless, the three papers cover nearly all the main types of sand dunes, i.e. longitudinal (Seif), barchan, transverse, dome-shaped, parabolic, and star dunes.

TABLE 2

Mechanical analysis (in percent) of barchan sands, Kharga Depression.

Particle size	Dune No. 1 Crest	Dune No. 1 Toe	Dune No. 2 Crest	Dune No. 2 Toe
Coarse Sand (+ 0.6 mm.)	5.8	8.6	2.9	4.7
Medium Sand (0.6-0.2 mm.)	59.0	56.6	54.8	67.4
Fine Sand (0.2-0.06 mm.	34.2	34.9	42.3	27.9

Unfortunately, the barchan dune of the White Sand dune field (New Mexico, U.S.A.) which was selected by McKee (1966, fig. 5) was not a typical desert barchan because of the following facts :

1. The dune was not a free isolated one, but it was attached to other dunes. This affects wind flow on dune body and consequently dune structure through the removal and deposition of sand.

2. The gypsum particles forming the dune body, with the aid of moisture, made the dune interior mostly firm (McKee, 1966, p. 25), with grains cohesive unlike the inside of quartz barchan dunes of Kharga. Relative firmness of gypsum dunes, as compared to the friability of quartz barchans, probably retards sand removal and migration of dunes.

3. Although the dune field of the barchan dune is under dominantly wind control, it is subject to a shift in wind direction. This wind regime resulted in a rather complicated internal structure in the barchan dune (McKee, 1966, fig. 8 A).

4. Although the structure of the White Sands barchan reflects wind conditions in the area, it does not exhibit any structural features concerning the stage of development of the dune.

8. BARCHAN STRUCTURES.

The two dunes selected for study are located quite near to one another (500 meters apart), 6.0 km. NNE of Kharga Village. Dune No. 1 is a fairly crescent-shaped mound. It is an embryonic, poorly-developed barchan. Its windward slope measures 25 meters, and its width (from horn to horn) is 15 meters. It has two very short, curved horns, and its lee side developed a small steep slip-face (70 cm. high). The windward slope is gentle and convex in outline in the upwind direction (Pl. I, A).

Dune No. 2 is a typical crescent-shaped mound. It is a well-developed barchan, reached the full-maturity stage of development (Embabi, 1967). The barchan measures 45 meters along the longitudinal axis from the brink to the toe, and 28 meters from horn to horn. The slip-face height was 4.0 meters, and as in other barchans, its slip-face was steep (34°) with its outline in ground plan concave downwind, whereas the windward side has a far more gentle slope, convex in outline in the upwind direction (Pl. I, B).

The structures of Dune No. 1 were clearly illustrated in the walls of the trench which was cut along its longitudinal axis (Fig. 3). Three types of structures were distinguished in the walls of the trench :

1. An ill-defined structure, where no stratification was clear in it. This is the structure of the core of the dune, which forms the middle lower part. The angles of the windward and leeward slopes were 15° and 16° respectively. It seems that this core represents the first phase of barchan development, i.e. the nuclie around which the dune grew up.

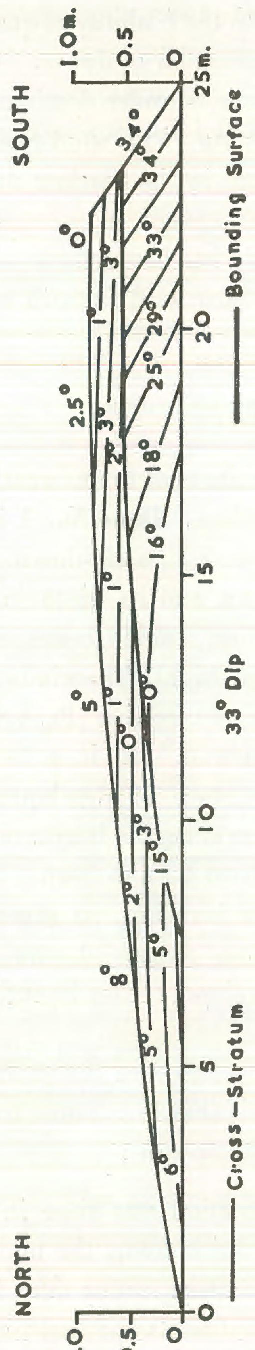

FIG. 3. — Dune No. 1 Cross-section, parallel to dominant wind direction from North.

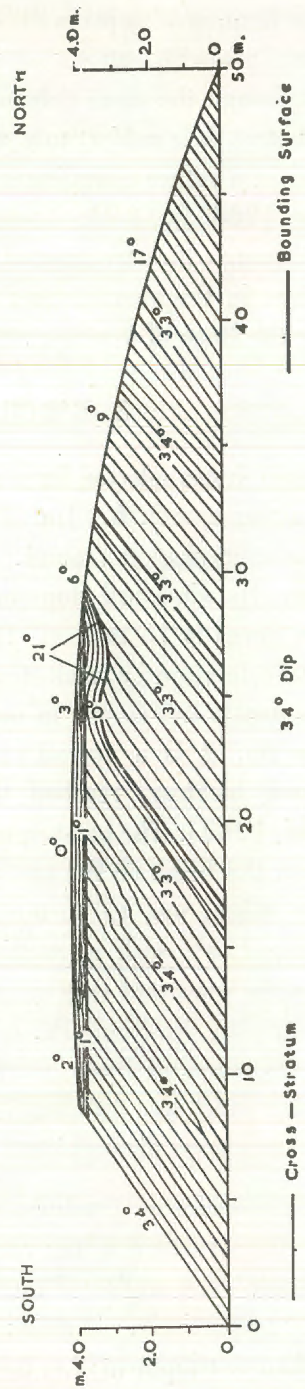

FIG. 4. — Dune No. 2 Cross-section, parallel to dominant wind direction from North.

2. A dipping structure, which was a continuous series of foresets of moderate to high dips (PL. III). Their angles was varying between 18° and 34°. Those beds having angles 18° to 29° apparently developed as slip-faces at an early stage of dune development, while those having angles 33° to 34° represent present-day slip-face. Thickness of beds varied between 5 to 10 cm. This is the structure of the front of the dune.

3. Horizontal to low-angle structure, which was composed of sets of strata whose angles varied between 0° and 10° (PL. IV). Thickness of beds was between 5 to 20 cm. This is the structure of the windward side. It is separated from the two lower structures by a nearly horizontal bounding surface (Fig. 3).

Basic structures of Dune No. 2 was clearly exposed in the walls of the trench cut approximately parallel to the dominant wind direction. From the windward margin to its slip-face was a continuous series of steeply-dipping beds that formed the lower $\frac{9}{10}$ of the dune, closely approached the angle of repose, for they ranged from about 31° to 34° (PL. V, A). They developed as slip-faces. Thickness of single beds varied between 5 to 20 cm.

Later deposits in the upper tenth (at the top) of the dune, consisted of thin (3-5 cm.), gently dipping to horizontal sets of strata, which contained cross-strata of moderate dip varying between 10° and 15° (PL. V, B).

Structural analysis indicated that :

1. The low angles of the cross-strata in the upper part of the dune suggest that these are upwind deposits. Thinness of units apparently resulted from periodic truncations by wind as upward dune growth became more and more difficult.

2. The steeply dipping beds of the lower part developed as slip-faces down which sand slides or on which it settles from suspension. The sliding sand consistantly builds up successive thin beds parallel — more or less — to the slip-face of the dune, i.e. dipping at 31°-34°. This means that the new beds cover the old ones and so on. Then as the dune moves foreward, these beds — in effect — move backward through the

dune body, i.e. beds forming the toe of the dune were — one day — exposed as slip-faces.

Two minor structures were also exposed in the walls of the trench. They seem worthy of note.

1. In the upper part, near the center of the dune, there were several trough structures, appearing as shallow small lenses (as much as 15 cm. wide and 5 cm. deep) in this plane (Pl. V, B and Fig. 5). Probably

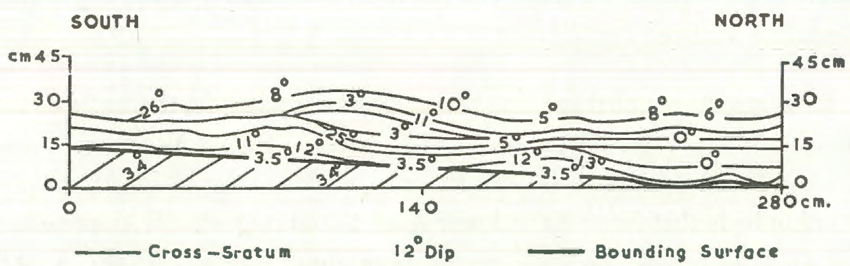

Fig. 5. — A detailed Cross-section of trough structures of Dune No. 2, parallel to dominant wind direction from North.

these structures indicate minor fluctuations in wind regime, and result in scour-and-fill structure. However, they formed only a very minor part of the total structure.

2. At the lower part of the dune, a few strata locally dipped at moderate angles (10°-12°) to windward, the reverse of normal structure (Pl. VI). These windward-dipping layers were preserved near the top of the dune. As indicated by the moderate angles of dip, these parts of the strata are possibly the result of periodic strong reverse winds from southerly direction.

9. TYPES OF CROSS-STRATIFICATION.

The three major types of cross-stratification, as described by McKee and Weir (1953, p. 385, and Table 4, p. 386), are represented in the two dunes.

The simple type, which has a non-erosional bounding surface, is by far the most common. In the two dunes, it has been observed that the steeply dipping sets of cross-strata were formed by deposition only, and the bounding surfaces are parallel downdip and nearly indistinguishable from stratification (Figs. 3 and 4). In this type of structure, it may be impossible to differentiate the units in some groups of sets.

The significance of this form of cross-stratification lies in that :

1. It represents slip-face deposits formed in the lower part of a dune through avalanching of sand.

2. It is an evidence that no sand removal occurs on slip-faces of barchan dunes.

3. Variation in thickness of strata or sets of cross-strata is due to the mode of sand deposition, which is by avalanching. It has been observed in the field that sand avalanches on barchan slip-faces vary greatly in size, resulting in differences in bed thickness.

The planar type of cross-stratification, which has a horizontal or nearly horizontal bounding surface was observed also in the dunes. From fig. 3 and fig. 4, it can be seen that tabular sets of cross-strata developed in the upper parts of the dunes. These sets of beds result from bevelling and subsequent deposition.

The trough structure, which has a curved bounding surface, is least common, and is represented in Dune No. 2 only. This type of cross-strata is wedge-shaped in which marked divergence of bounding surfaces occurs. As can be seen from fig. 4, it developed only on the Dune crest. It results from channeling by strong winds (periodic gusts) and subsequent deposition. This is in accordance with McKee findings in the White Sands, New Mexico (1966, p. 57).

The presence of this type of cross-strata on Dune No. 2 and its absence on Dune No. 1 is an evidence that barchan dunes become complicated in structure as cycle of development advances, due to exposure to winds of different velocities and regimes for longer periods.

10. RELATION BETWEEN STRUCTURAL FEATURES AND TYPES OF CROSS-STRATIFICATION AND STAGE OF DEVELOPMENT.

Previous studies on cycle of barchan development (Bagnold, 1941, p. 105-112; Coque, 1962, p. 334-346; Embabi, 1967, p. 257-260) were concerned with the morphological characteristics of the barchan at the various stages of development, but no attempt has been made to relate the morphological characteristics of each stage of development with the internal structures of barchans. This was probably due to the fact that little was known about structure of barchans.

The former analysis of the structures and cross-stratification in the two barchans reveals that although they have numerous structural features in common, each of them has some features that are characteristic of that stage of development.

The common features are the following :

1. Numerous sets of cross-strata, which have dip surfaces attaining the angle of repose (30°-34°), face downwind. They form a dipping structure.
2. Low-angle to horizontal sets of strata, which dip upwind, form a horizontal structure.
3. Bounding surfaces which separate the two structures are horizontal or dip upwind at low-angle.

The distinctive features of each dune are the following :

1. Dune No. 1 had an ill-defined structure, where no stratification was clear in it, forming the core of the dune. Its characteristics, which were 10 m. for length, 30 cm. for height, and 15° and 16° for angles of the windward and leeward slopes respectively, suggest that this core represents the nuclie around which the dune developed. This means that barchans start as small mounds of sand without any specific

structure. This conclusion is in accordance with field observations of the presence of small sand mounds having nearly the same morphological characteristics of Dune No. 1 core at the beginning of barchan belts in Kharga and Dakhla Depressions.

2. The dips of the foresets of Dune No. 1 decrease upwind from 34° to 18°. Those beds having angles between 18° and 29° apparently deposited during the phase of development which followed the formation of the core, i.e. before the leeward slope attained the angle of repose, while those beds having angles between 33° and 34° developed as slip-faces when sand accumulation on the leeward slope reached the angle of repose.

These two distinctive structural features of Dune No. 1 and its morphological characteristics suggest that it has reached *the youth stage of development,* and that this stage can be divided into the three following stages :

a) *Early youth :* the deposition of a sand mound with no internal structure.

b) *Mid-youth :* the development of medium-angle (18°-29°) foresets on the leeward side.

c) *Late youth :* the formation of steeply-dipping (31°-34°) beds as slip-faces attaining the angle of repose. During this phase and phase (b) the low-angle structure on the upper part of the dune was formed.

3. The dips of the foresets of Dune No. 2 were consistent in all the lower part of the dune body, varying between 31° and 34°, i.e. attaining the angle of repose. This fact, the morphological characteristics of the Dune, and the conclusion concerning the phases of development of Dune No. 1, suggest that *Dune No. 2 passed the late youth phase and started another phase in a new stage of development which is early maturity.*

4. There were two micro-structures (reversed dipping beds and scour-and-fill structure) in Dune No. 2. These micro-structures develop under the effect of special wind fluctuations. Their preservation in Dune No. 2 suggests that it was exposed for a long period to wind action after entering

the early maturity stage. This means that it attained an advanced phase of development in maturity stage, which can be described as *mid-maturity*.

The conclusion which can be drawn from the foregoing analysis is that the two dunes represent one form of desert dunes, i.e. barchans, but at two different stages of development which are : late youth for Dune No. 1, and mid-maturity for Dune No. 2.

11. COMPARISON WITH STRUCTURES OF SOME OTHER AEOLIAN FORMS.

Barchans of the Kharga Depression are the result of sand being transported in one direction only. Structures of some other dunes like transverse and dome-shaped dunes which are formed also by unidirectional winds were discussed in detail by McKee (1966). Other dunes of some other parts of the world are modeled by multidirectional winds. Few of such dunes, like Seif Dunes of the Fezzan in Libya (McKee and Tibbitts, 1964), Reversing Dunes of San Louis Valley in Colorado (Merk, 1960), and Star Dunes near Zalim in Saudi Arabia (McKee, 1966), have been cross-sectioned and analysed.

Little is known about the structures of other aeolian forms, especially the micro-forms caused by unidirectional wind like granule ripples, or by multiple wind directions like small stable dunes which develop in the lee of fixed obstacles (they are called sand shadows by Bagnold, 1941, p. 218 ; tail dunes by Kadar, 1934, p. 474, and dune d'obstacle by Coque, 1962, p. 332). The author had the opportunity to examine the internal structure of a small stable dune (2.0 m. long) and a granule ripple, considered to be typical of the two forms, in the Tihama Coastal Plain of Saudi Arabia. To expose sections of cross-strata, the granule ripple was cut (from crest to base) along its longitudinal axis, parallel to the prevailing wind, and the stable dune was cross-sectioned (from crest to base) at right angles to its longitudinal axis.

A. Stable dune :

Previous studies on stable dunes (Bagnold, 1941, p. 190 ; Coque, 1962, p. 333 ; Embabi, 1967, p. 230) indicated that when the

prevailing wind strikes the obstacle of the dune, it is divided into three air streams : one climbs up the obstacle and the other two streams pass along its sides (Fig. 6). The stable dunes develop in a direction intermediate between the two side streams because sand is deposited alter-

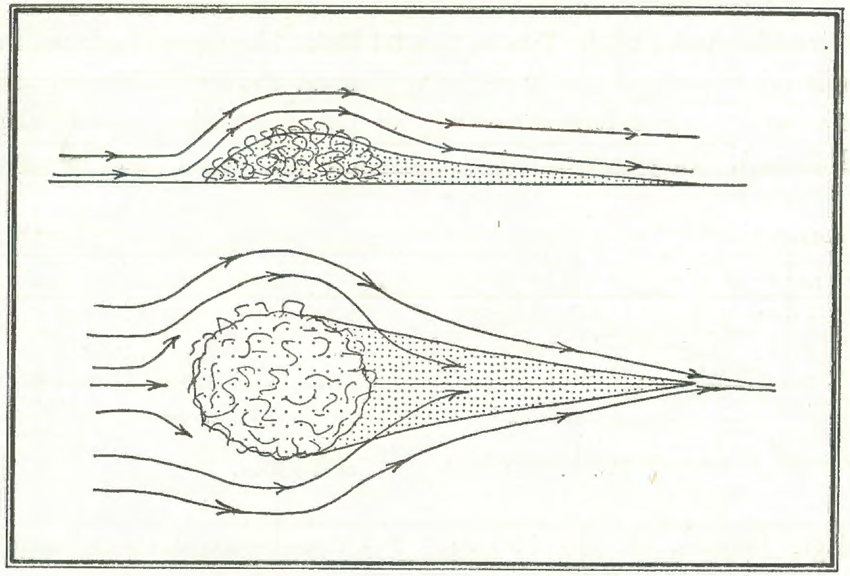

Fig. 6. — Wind Dynamies on a stable Dune [after Embabi, 1967, fig. 71].

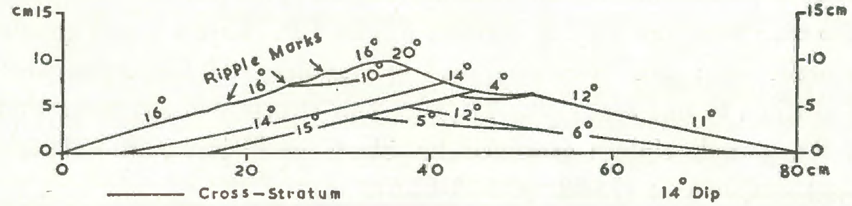

Fig. 7. — Stable Dune Cross-section.

nately (by the side streams) on opposite sides of the dunes. The pattern of cross-stratification, in such dunes, which can be seen from Fig. 7 and Pl. VII A, consists of several sets of laminae (2-5 cm. thick), dipping moderately (12°-15°) in opposite direction. Therefore, stratification dips normal to the dune body, but reverse to wind direction, because it forms by sliding of sand down the side which at any particular time is a slip-face.

This structure resembles that of Seif Dunes of the Fezzan in Libya, which develop under the effect of winds from two directions (McKee, 1971, Fig. 4 B, p. 405).

B. Granule ripple :

Granule ripples of the Tihama Coastal Plain, like those developed in some other parts of the world, e.g. Kharga, Dakhla, California, are large wind ripples formed partially of grains attaining granule size (2-3 mm.). They vary in height between 7 and 15 cm., and in wave length between 70 and 150 cm. The dimensions of the examined granule ripple were 7 cm. for height and 75 cm. for length.

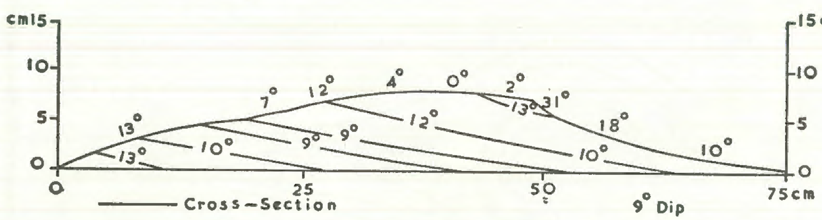

Fig. 8. — Granule ripple cross-section.

The cross-section of the ripple (Fig. 8 and Pl. VII, B) reveals that it has a prominent internal structure of well-developed forset laminae (2-5 cm.) with dips varying between 9° and 12°. Layers varied greatly in grain size : some were composed of granules, and the others were of medium to fine sands (Pl. VII, B). This structure is similar to that of the granule ripples examined by Sharp in Mojave and Colorado Deserts, California (1963, p. 633-634).

Analysis of the structure of the granule ripple indicates that the large grains travel up the windward slope by surface creep and tumble down the lee side forming a thin granule bed. Deposition of finer material from saltation and suspension might occur on the granule layer during times of lesser wind velocities. If wind speeds up again, granule grains are moved again up the windward slope and tumble down the lee side forming another layer of large grains. This means that successive thin layers — parallel more or less to the lee side — are built up, and the new

layer cover the old ones. This is an indication that granule ripples move — but slowly — foreward, due to the fact that large grains need high wind velocities to be moved by surface creep. However, this process of developing this type of stratification is similar to that of barchan foresets, which was discussed in a former part of this paper.

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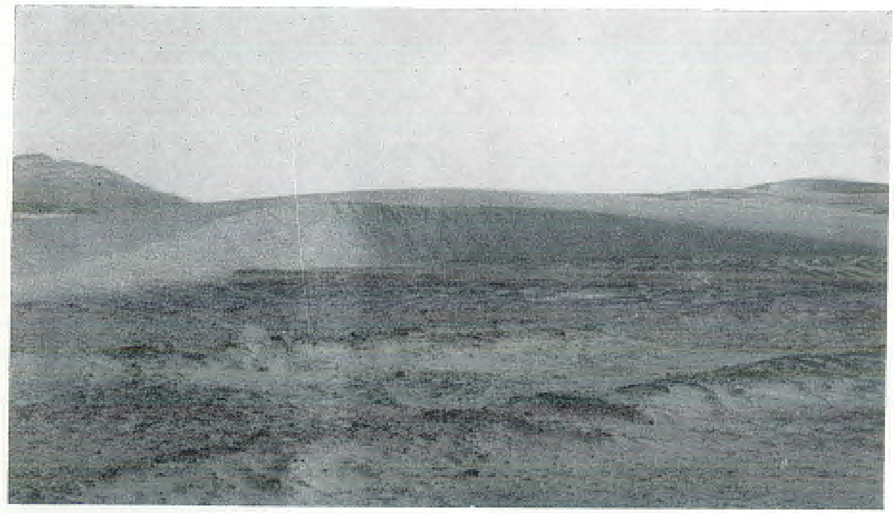
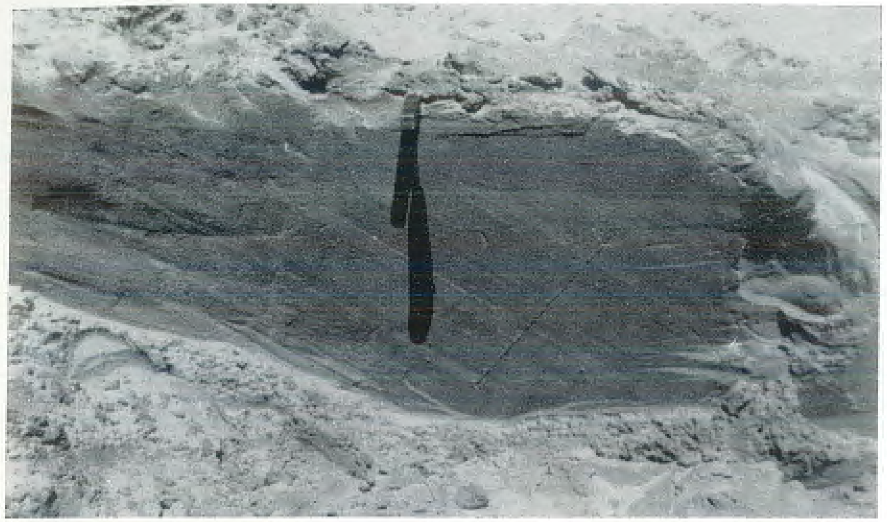
A. — A photograph of Dune No. 1, which is an embryonic, poorly-developed barchan.



B. — A photograph of Dune No. 2, which is a well-developed barchan.

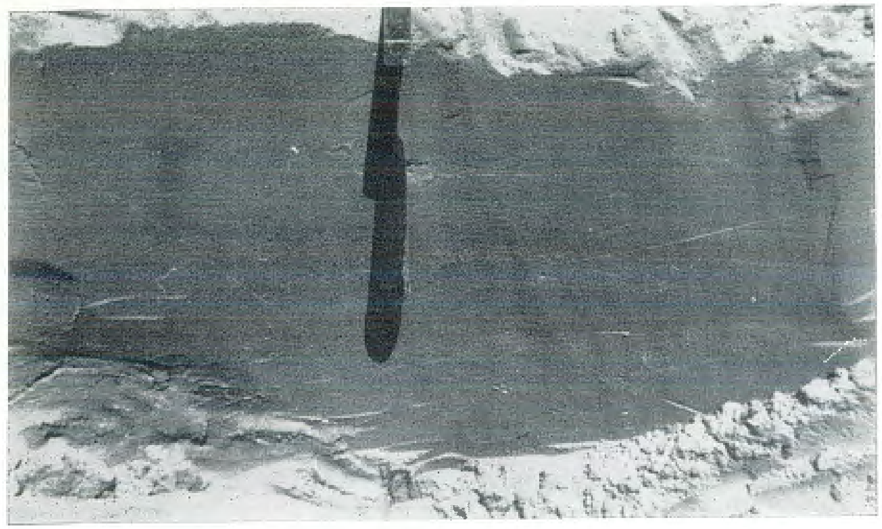
A. — Filling a tanker with water used in cutting the trenches in dunes.

B. — Two stages in digging the trench along the longitudinal axis of Dune No. 2.

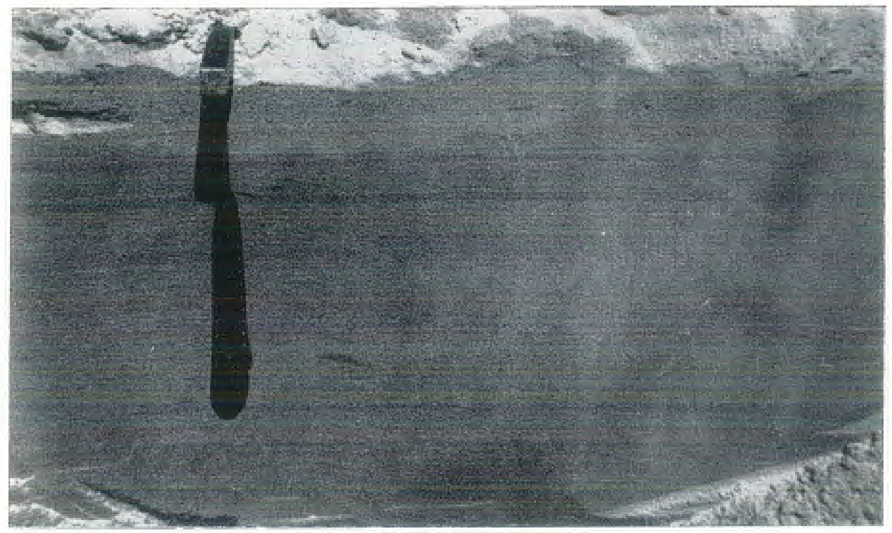


A. — Horizontal bounding surface separating nearly flatlying beds from steeply-dipping strata ; near leeside of Dune No. 1.

B. — Micro-differences in texture (grain-size) represented in successive foresets or topsets of Dune No. 1.



A. — A photograph showing the increasing thickness of the horizontal topsets of the windward side of Dune No. 1.

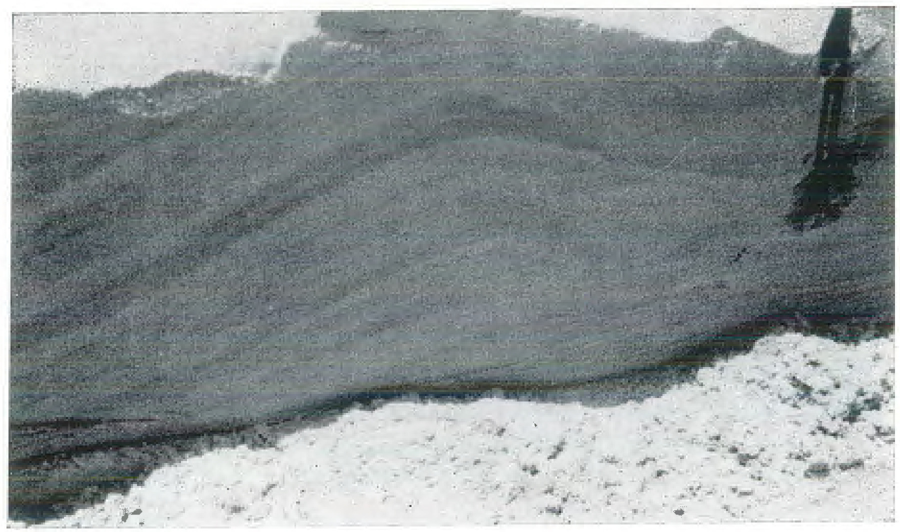


B. — Stratification in the wall of the trench of Dune No. 1, normal to main wind direction, with no apparent dip; located at the windward side.

A. — Thin sets of cross-strata dipping steeply to leeward in Dune No. 2; near leeward side (pen is 18 cm. long).

B. — Nearly horizontal bounding surface, in the upper part of picture, separating two sets of cross-strata in Dune No. 2. Note the micro-trough structures near dune crest, and irregularity in some of the steeply-dipping beds.

A. — Irregular or contorted layers with reversed dips in Dune No. 2; located in the middle part of the dune near surface.



B. — A detailed photograph of a contorted set of layers with reversed dips in Dune No. 2.

A. — A cross-section of a stable dune showing several sets of laminae dipping in opposite direction; the Tihama coastal plain, Saudi Arabia.

B. — A cross-section of a granule ripple showing a well-developed dipping structure; the Tihama coastal plain, Saudi Arabia.

SOME REMARKS ON THE SEASONALITY OF RAINFALL OVER THE SUDAN

BY

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The workers in the field of climatology have always been faced with the difficulty of defining the wet months or seasons. The wide differences in the global rainfall regions and characteristics make such a task one of the most controversial aspects in this branch of knowledge. Several techniques have been suggested for dealing with this problem but non seem absolutely satisfactory for a world-wide application. However, some of the available techniques may be regarded as useful on a local scale. Of the latter group, the technique deviced by Cook in 1946 seems to be suitable for areas like the Sudan where the rainfall averages show considerable spatial variations. He suggested that under the WET category, one should include all the months during which at least 10% of the mean annual rainfall is received. On the other end of the scale, a dry month can be defined as the month that witnesses less than 5% of the mean annual rainfall. In between these two extremes lie the transitional months which should therefore include the months during which 5-10% of the mean annual rains are experienced.

In the present paper, Cook's (1946) system has been applied in an attempt to identify the wet seasons in the different parts of the Sudan with the idea of presenting new maps of the rainfall seasonality in the Country. The work is based on the recognition of the commencement and the termination of the wet season. The commencement of the wet season coincides with the first month during which the ratio of the monthly to the annual rainfall exceeds the 10% level. On the hand,

the termination of the wet season is marked by the month after which the monthly rainfall values are always less than 10% of the annual mean.

The application of these techniques reveals that the commencement and the termination of the wet season differ considerably between the

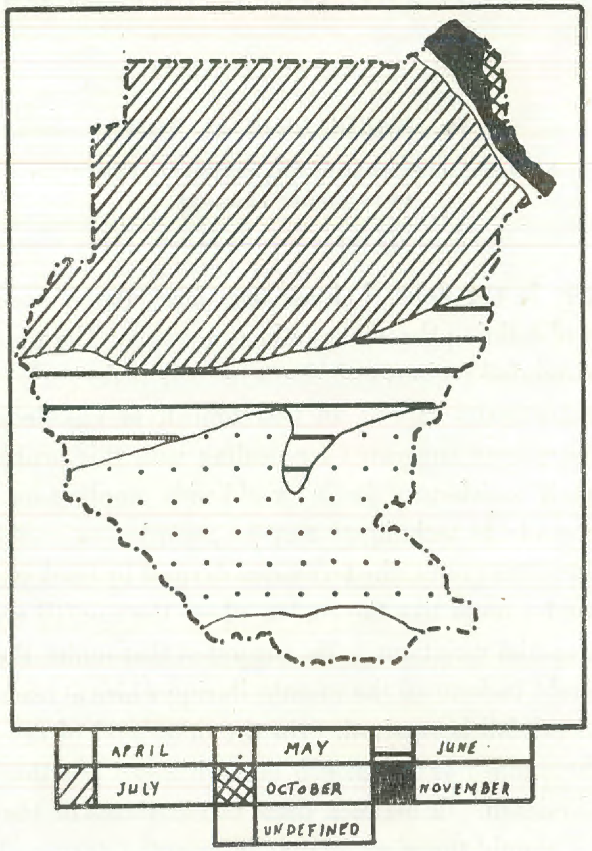

Fig. 1.— The Commencement of the wet season.

different parts of the Sudan. This can be illustrated by figures 1 and 2 which are self-explanatory. However, one may notice that for the Country as a whole, the commencement of the rainy season spreads over a longer time-scale than its termination.

Further to this, the superimposition of these two maps provide a suitable means for determining the duration of the rainy season in the

Sudan. Such a season will include all the months during each of which at least 10% of the mean annual rainfall is received. Excluding the Red-Sea region, seven different rainy seasons may be recognized, (Fig. 3). The duration of these rainy seasons ranges between seven months in the

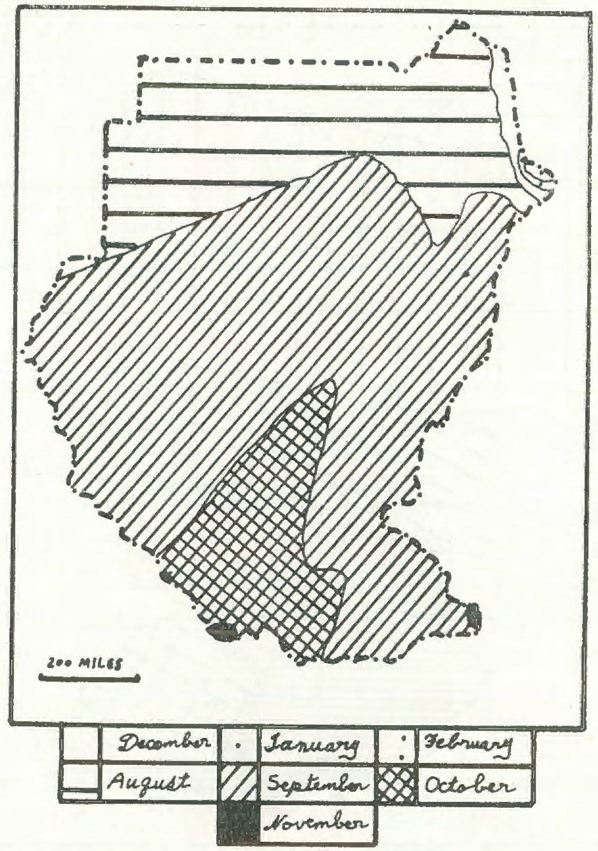

Fig. 2.— The Termination of the wet season.

extreme S.W. and less than two months in the vicinity of the northern frontier. As is shown in figure 3, region A has the longest rainy season that extends between April and October inclusive. In regions B and C the rainy season extends over six months, but the seasons are not quite coincident. In region B the season starts during April and lasts up to September. These two dates are in fact one month earlier than in region C. Although region D lies within almost the same latitudinal limits of region

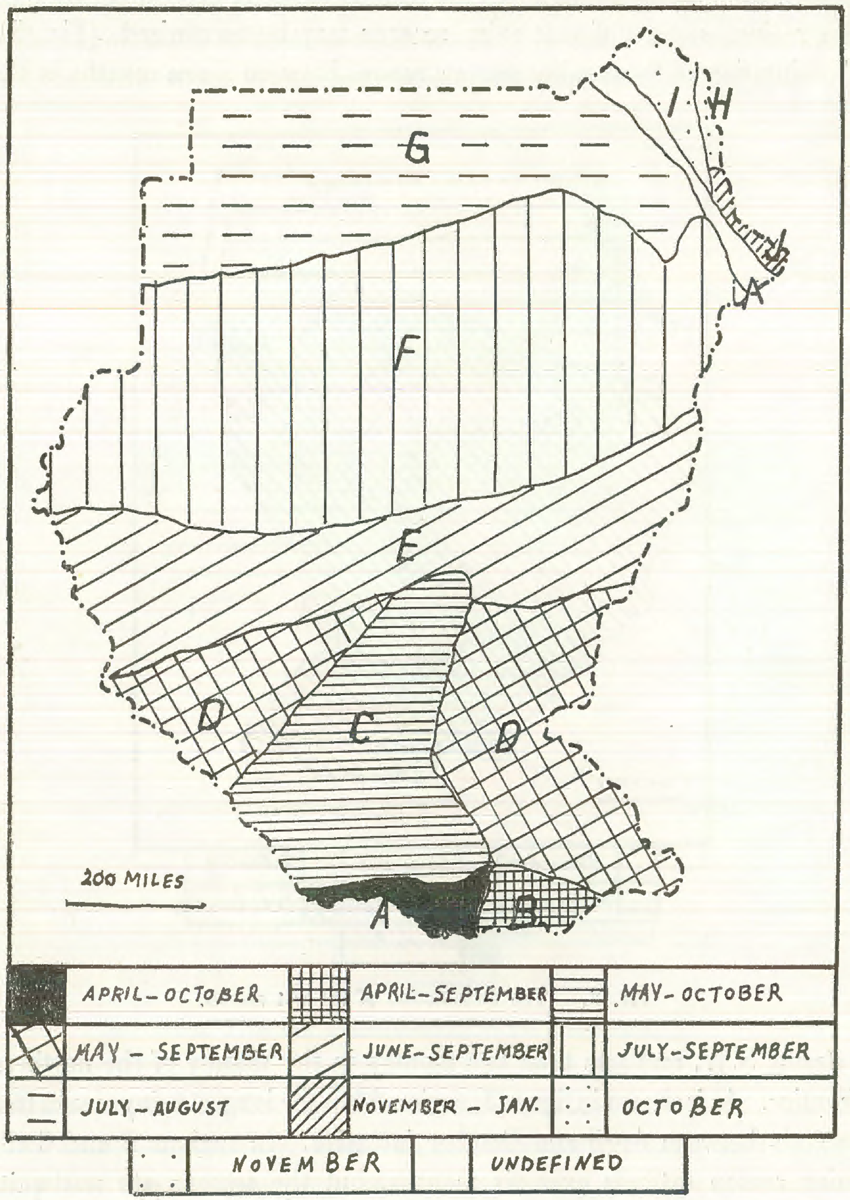

Fig. 3.— The rainy seasons of the Sudan.

C, yet its rainy season spreads over five months only. Here the commencement of the rainy season coincides with that of region C but the termination of the season takes place during September which is a month earlier than in the previous region.

As one moves further north, the duration of the rainy season decreases steadily thus it covers four months in region E, three months in region F and less than two months in region G.

Despite the validity of the above regionalization, yet one finds some logic in Gregory's (1964) belief that it is more desirable to have a group of months that may be considered as the general rainy season for the whole country rather than having different rainy seasons for the different parts of the same country. Such months may be taken as those during each of which at least 10% of the annual rains fall everywhere in the country. The months of July, August and September are the only months that meet these strict conditions and so they form together what may be called the «general rainy season» of the Sudan, however confusing the term may be.

The degree of rainfall concentration during the suggested season may be determined by expressing the total rainfall received during July, August and September as a percentage of the mean annual rainfall. The spatial distribution of this ratio is provided on figure 4 which shows that almost three quarters of the country receive more than 60% of their annual rains during the period July-September inclusive. The ratio increases to 75% over the Central Sudan and rises up to 100% near the northern frontier. The lowest ratios, however, are found over the Southern quarter of the Country where the ratio may drop below the 40% level in the vicinity of the S.W. border. The latter case is an indication of a better distribution of the annual rainfall.

The intensity of the monthly rainfall during the «general rainy season» may be determined by dividing the total rainfall received by the number of the months involved, i.e. three months. This is displayed on figure 5. The highest intensities are found in the extreme S.W. parts from where they decrease gradually northward showing marked responses to the topographical influences of Jebel Marra, the Nuba mountains and the Red Sea hills.

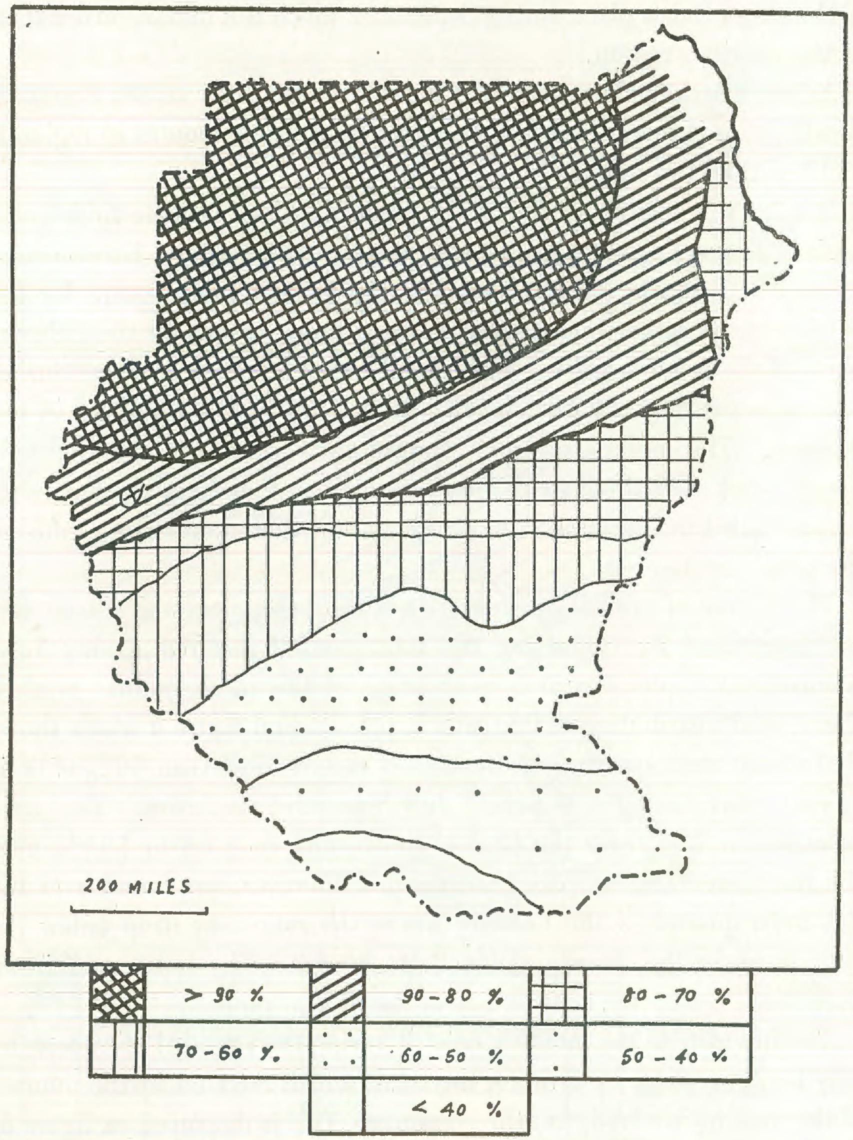

Fig. 4. — Total July, August and September rainfall as a percentage of the mean annual rainfall.

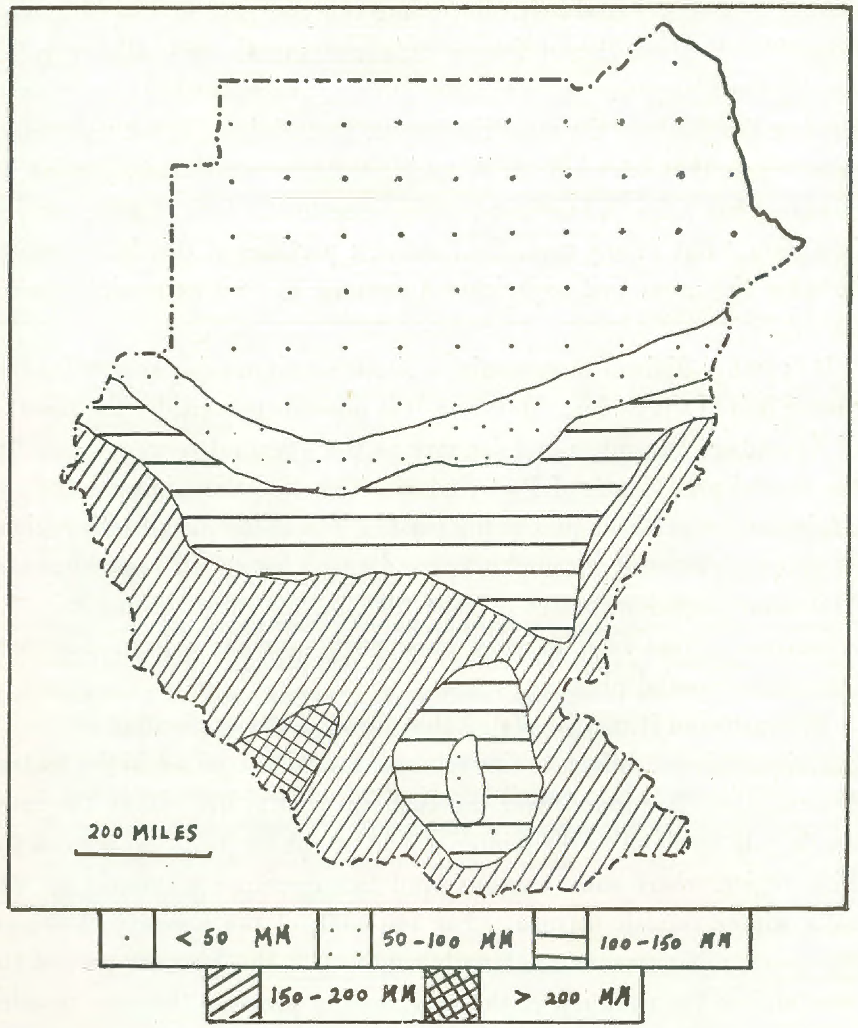

Fig. 5. — Monthly rainfall intensity during the general rainy season.

The conditions over the Red Sea region are very different from those over the other parts of the Country. Using the same technique of superimposing the map of the termination of the wet season upon that of its commencement it is possible to determine the variations of the rainy seasons over this coastal belt. Here, four rainy seasons may be identified (Fig. 1). Regions H and I have only one month each that may be classified as a rainy month. These are October and November respectively. Further South along the coast lies region J which has the longest winter rainy season that extends from November to January inclusive. Region K, however, has been drawn very roughly due to the lack of adequate information. But in any case, the Southern portions of this latter region includes the areas that experience a summer as well as a winter rainy periods.

It is rather difficult to recognize a single common rainy season for the coastal belt of the Sudan. However, it is possible to consider the months of November, December and January as the «general rainy season» for the coastal area South of Port Sudan. This limitation implies the exclusion of the northern part of the coast as well as the inland hilly region. The monthly intensity during this period ranges between 20 and 40 m.ms. This same period witnesses at least 60% of the mean annual rainfall; a percentage that rises to more than 80% over the extreme southern part of the coastal plain.

In conclusion it may be stated that through the application of Cook's technique, eleven different rainy seasons may be recognized in the Sudan. Four of these are found over the Red Sea coastal belt where the rains are largely confined to the winter season except for a limited area in the hilly region where some stations tend to experience a summer as well as a winter rainfall maxima. For the bulk of the Country, however, the seven rainy seasons are largely confined to the Summer part of the year and so the duration of the rainy season provides the only possible distinction. It is worth mentioning that all these variations can easily be explained in terms of the nature and the movements of the intertropical convergence Zone (I.T.C.Z.). The slow advance and the rapid retreat of the I.T.C.Z. corresponds with the slow commencement and the rapid termination of the wet season over the Sudan. Also the characteristic northward extension of the I.T.C.Z. along the western foothills of the Ethiopian plateau explains the early setting of the rainy season near the Eastern border relative to the areas that lie further inland on the same latitudes. Over the coastal belt, the winter rains are largely related to the intensification of the Saharan and the Arabian anticyclones and their respective on-shore winds. The double rainfall maxima over some of the hilly stations near the coast is mainly due to the exposure of these stations to the winter rains associated with easterly winds from over the Red Sea as well as to the summer rains associated with the I.T.C.Z. and the consequent northward advance of the southwesterly moist winds.

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WADI EL-RAIYAN:
A NATURAL WATER RESERVOIR
(WESTERN DESERT, EGYPT)

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LOCATION AND GEOMORPHOLOGY

Wadi El-Raiyan is a small enclosed and curiously shaped (clover-leaf like) depression located at 25 km. southwest of El-Faiyum [1], between lat. 28° 15' and 29° 17' N, See Fig. 1. The depression, discovered by Linant de Bellefonds (1873), is cut out of the white, nummulites rich, limestone of the Eocene, Caton-Thompson and Gardner (1934). The lowest point of the floor of the depression is at -60 m. below sea level. The area at -60 m. contour is 22 km^2, at zero (sea level) contour its area is 301 km^2 and at + 30 m. contour it is about 703 km^2. Its maximum breadth is 25 km. at long. 30° 12' and 30° 32' E.

Wadi El-Raiyan may be roughly divided by an imaginary line into a northern part and a southern part, Fakhry (1947). The northern part is called Wadi El-Raiyan El-Soghayer (i.e. the small) where no running springs exist (in the last century there were two springs in this part, now burried under sand). The southern part is called Wadi El-Raiyan El-Kebear (i.e. the great) in which there are three springs.

Wadi El-Raiyan Depression is organized into three geomorphological units (Abdel Baki, 1972) namely :

a) depression edges, *b*) depression floor, and *c*) sand dunes.

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[1] El-Faiyum is a province at 92 km. southwest of Cairo. It has an area of 1350 km^2.

a) Depression edges :

The depression edges are defined by zero contour. The edges are bounded from all sides by high lands (up to R.L. + 100 m. and R.L. + 150 m.) which are characterized by lack of vegetation and absence of drainage lines.

b) Depression floor :

The floor is organized topographically into a number of depressions and scarplets having different elevation. The lowest point (R.L. -60 m.) extends some 5-6 km. Such floor is, for most part, covered with sand bodies which are relatively high, steep and difficult to cross. In the south western portions there are a few mineral springs and the floor is covered with scrub and palm trees. In general, the floor of the depression is characterized by a gentle slope towards the lowest portion.

c) Sand dunes :

The surface in Wadi El-Raiyan Depression is covered with accumulation of drift sand. These shifting sand accumulation typically take the form of longitudinal and parallel dunes (20-30 m. high) extending along the direction of prevalent NNW wind and continuing for long distances. Such dune sands are probably formed within Holocene period as a result of disintegration and transportation of friable sand stones. «Between the dunes is a fairly hard undulating sand flat affording an easy route», Beadnell, 1905.

Between El-Faiyum and Wadi El-Raiyan Depression there is a ridge (R.L. + 10 to R.L. + 34 m.) of about 15 km. long and 10 km. wide. The ridge is formed of fissured Eocene limestone with surficial gravelly layer (Beadnell, 1905).

GEOLOGICAL HISTORY AND ORIGIN

Ball (1927), Ibrahim (1956), El-Shafei (1957) and Said (1960) show that the depressions of the Western Desert of Egypt (e.g. Wadi El-Raiyan, El-Qattara, ... etc.) are natural excavations not subsidences and that wind has been the main excavating agency.

The geological history of Wadi El-Raiyan Depression is given by Fox (1951) as follows (p. 1) : «From 100 million years northern Egypt has been a marine area-first estuarine conditions slowly gave way to marine, and then returned to fluviatile conditions before the Miocene period, 25 million years ago. Subsequently, a Pliocene fiord tongued up to a lake region in the area that is now El-Faiyum and Beni Suef Provinces. Owing to the Great Ice Age in the northern hemisphere, with no vast a quantity of the sea water stored in the ice sheets, and to the immense weight of the ice, the water of the Nile cut northward into the Mediterranean in pleistocene time about 250,000 years ago. These waters also had flooded a basin in El-Faiyum probably just before the break through to the North. Subsequently, perhaps 100,000 years ago, the Nile once more flooded El-Faiyum and over-flowed into Wadi El-Raiyan».

At the time of the latter flooding, Wadi El-Raiyan was a shallow depression in a desert area. With the strong winds from the north, armed with sand, the water in the Wadi El-Raiyan was rapidly evaporated. The scouring action of the sand-laden winds has cleared the Wadi El-Raiyan in its present size and depth, and exposed the Middle Eocene strata now seen on the floor of the basin.

Tamer (1968) summarises the geology of Wadi El-Raiyan in three periods, viz :

I. Pre-Pliocene time, Wadi El-Raiyan forming an upfold area oriented probably in the NW-SE direction, this was complicated by local fold structure oriented NE-SW,

II. Pliocene and early Pleistocene times; formation of the depression areas at Wadi El-Raiyan initially by tectonic factors and chemical weathering. Faulting accounted; presumably, for the lowering of land surface in the depression areas. These became filled with water, as a part of an extensive lake formed in the region when the level of the Nile reached R.L. + 45 m.,

III. Late Pleistocene and Holocene times, the depression became almost dry and, consequently, subjected to wind erosion and formation of sand dunes.

The historic origin of the word «Raiyan» is discussed by Fakhry (1947), pp. 4-5 : «Rayyan is an Arabic word which means the «watered one» or «the luxuriant» a suitable name of this Wadi which is covered with vegetation at many spots and whose subsoil has water which can be found at less than 2 m. A beduin legend gives another explanation. The ruins of ancient buildings are the ruins of the houses of a powerful king called «El-Rayyan» and his soldiers who lived here.

Coptic literature gives an interpretation of the name of the Wadi that is different. It is stated in the biography of Anba Samuel of Kalamoun that he used to go from time to time to worship alone in this Wadi and he found the word «El-Rayyan» in the Arabic text on Abu Salih the Armerian Warship. The name «Rabana» is a possible one, this is affirmed by its mention in the *Horris Papyrus* in connection with the Libyan war of Ramesses III.

CLIMATE AND WATER SUPPLY

Wadi El-Raiyan is located in the Western Desert of Egypt which is considered «par excellence the most arid among the desert regions of the world», Mitwally (1953). Table 1 shows the climatic normals of El-Faiyum Province, the nearest meteorological station to Wadi El-Raiyan.

Rainfall is scanty (*c* 14 mm./year). Ground water is the main source of water supply for the depression. Ball (1927) believes that under large areas of the Libyan (Western) Desert of Egypt there is a continuous sheet of subterranean water. In the south-western portion of Wadi El-Raiyan Depression there are three springs (Fig. 2) deriving their water from the same underground source «which is believed to be the fissured Nubian Sandstone about 600 m. beneath Wadi El-Raiyan», Fox (1951). The springs are as follows :

A) East spring, known as «Ain [1] El-Bahariya (29° 6' N Lat. 30°18' E long., R.L. + 24 m.)». Its water outflow is 0.5 gallon/minute and it has an odour of sulphuretted hydrogen. The solids in solution have been given as between 8,000 and 4,000 ppm. of which common salt

[1] Ain is an Arabic word for spring.

TABLE 1

Meteorological Data of El-Faiyum during the period 1931-1960 (taken from the Climatological Normals of Egypt, 1960).

Month	Temperature °C Max.	Temperature °C Min.	Relative humidity (%) 6 A.M.	Relative humidity (%) 12 at noon	Relative humidity (%) 6 P.M.	Evaporation per day in mms (Piche)	Rainfall (mm) Total	No. of days with rain 0.1	No. of days with rain 1.0
January	20.3	6.1	72.0	42.0	69.0	3.2	0.9	0.6	0.5
February	22.0	7.3	68.0	37.0	59.0	4.3	1.9	0.7	0.7
March	25.1	9.9	59.0	30.0	50.0	5.8	1.6	0.6	0.4
April	30.1	12.9	54.0	23.0	43.0	8.3	0.7	0.2	0.1
May	34.0	17.2	49.0	21.0	35.0	8.2	1.2	0.1	0.1
June	35.8	19.7	56.0	22.0	34.0	9.4	0.0	0.0	0.0
July	36.7	21.2	63.0	26.0	38.0	11.4	tr.	0.0	0.0
August	36.5	21.9	67.0	28.0	43.0	9.9	0.0	0.0	0.0
September	33.7	19.6	74.0	32.0	52.0	8.1	tr.	0.0	0.0
October	31.2	17.1	69.0	34.0	56.0	6.7	1.0	0.3	0.2
November	26.5	13.1	83.0	39.0	64.0	4.4	0.7	0.3	0.2
December	21.8	8.5	75.0	44.0	69.0	3.1	5.7	1.4	1.1
Mean annual	29.5	14.5	66.0	32.0	51.0	6.9	—	—	—
Total	—	—	—	—	—	—	13.7	4.2	3.3

represents 75% ; carbonates and sulphates (3 : 1) of calcium make up most of the remainder with some magnesium salts.

B) Middle or north spring, known as «Ain El-Wastaniya», 4 km. southeast of Ain El-Bahariya (R.L. + 20 m.). The water of this spring is clear and pleasant to drink without odour of sulphuretted hydrogen. The water discharge is 1.5 gallons per minute. It contains 3,500-4,000 ppm. consisting of 75% common salt and other components like those of the water of Ain El-Bahariya.

C) South spring, known as Ain El-Qibliya, a little more than 3 km. south by east from Ain El-Wastaniya (R.L. + 25 m.). The water discharge is 4.5 gallons per minute and it gives off an odour of sulphuretted hydrogen. The salinity of water is about 3,800 to 3,500 ppm. solids in solution.

The water of these springs is derived from «remote collecting areas and are therefore warm (26° C)», Ball (1927).

There is evidence that all these springs have been long in use, as their water is drinkable. In the first and second centuries A.D. the depression was inhabited and a part of its land was cultivated, «Remains of houses and tombs, fragments of broken earthenware, pieces of fossil-wood and a stone of chapel were found around the area of the springs, but the main ruins are scattered around Ain El-Wastaniya», Fakhry (1947).

The vegetation cover in Wadi El-Rayan Depression is confined to areas around the springs where soil moisture is high enough to maintain plant life. «Beside the trees of date-palm (*Phoenix dactylifera*) and sayal (*Acacia raddiana*), there are bushes of tamarisk (*Tamarix* sp.), gardag (*Nitraria retusa*), bawal (*Zygophyllum album*), Halfa grass (*Desmostachya bipinnata*), Agul (*Alhagi mautorum*) and Shoka (*Fagonia arabica*)», Fakhry (1947)».

WADI EL-RAIYAN : A FLOOD WATER RESERVOIR

Before the establishments of the High Dam (1960-1970), 15 km. south of Asswan, See Fig. 1, most of Nile water during the flood season (July-September) found its way to the Mediterranean Sea. The capacities of dams on the Nile course at Asswan and Esna (1000 and 750 km. south of Cairo) are limited. If more reservoirs could be constructed, more land in Egypt could be reclaimed and tilled. Wadi El-Raiyan Depression was found to be suitable for being converted into a natural reservoir basin or «as escape and storage and flood control», Hurst *et al.*, (1946).

The history of the project goes back to 1882 when Cope-Whitenhouse suggested the use of the depression as a reservoir. Many researches and studies followed in which Schweinfurth (1886); Liernur *et al.* (1888); Garsten (1894); Willcocks (1899); Beadnell (1903); Azadian (1930); Little (1936); Mc Dounald (1945); Hurst *et al.* (1946) and several others took part. The project aimed at constructing a barrage across the Nile 11 km. south of Beni Suef [1] and to bring an inlet channel from

[1] Beni Suef is a province at 120 km. south of Cairo.

the Nile at the site of the Barrage to Wadi El-Raiyan Depression across 24 km. of cultivated land and 12 km. of desert (barren) country, see Fig. 2. «The right size of the inlet channel is computed for a flow of 70,000 m^3 water a day during the flood days (90 days); Mc Dounald (1945). Garsten (1894) noted that it would take 8 years to fill the reservoir up to + 30 m. above sea level. This was confirmed by Willcocks (1899) who estimated that in the first year the water would reach to R.L. -18 m., in the second year to R.L. -3 m., in the third year to R.L. + 7 m., in the fourth year to R.L. + 13 m., in the fifth year to R.L. + 18 m., in the sixth year to R.L. + 22 m., in the seventh year to R.L. + 26 m., and in the eighth year to R.L. + 30 m. The area of the reservoir at R.L. + 30 m. is about 703 km^2 (170,000 feddans [1]), Beadnell (1905). At that level Fox (1951) estimated that the reservoir will hold roughly 21 km^3 water.

«To utilize the water of the reservoir there must be a channel back to the Nile (outlet channel) capable of discharging 20 million m^3 water per day», Liernur *et al.* (1888). The outlet channel would follow the inlet channel up to Bahr Yusuf [2] then from Bahr Yusuf itself to Lahun, some 28 km., then eastward to the River Nile at 3 km. south of El-Wasta [3], see fig. 2.

It was estimated that it would take about three years to make the inlet and outlet channels of this reservoir and associated works in the Nile Valley, and 8 flood seasons to fill the reservoir a total of 11 years before the reservoir be fully capable of supplying irrigation. The costs of the project were estimated by Liernur *et al.* (1888) to be L.E. 1,302,095 and by Garsten (1894) to be L.E. 3,700,000.

Advantages of the Project :

Fox (1951) states (p. IV) «As Egypt is the gift of the Nile, Wadi El-Raiyan is the gift of the Western Desert». The utilization of Wadi

[1] Feddan : Egyptian acre with an area of 4200 m^2.
[2] Bahr Yusuf is the canal that carries Nile water to irrigate El-Faiyum Province.
[3] El-Wasta is a town 90 km. south of Cairo.

El-Raiyan as flood-water reservoir would have many advantages including the following :

1. Protection of Egypt against disastrous floods as it would fill during the time of maximum Nile flood, during the low-water season (April-June) the stored water would return to the Nile for use.

2. The stored water estimated to be capable of augmenting the volume of the Nile water and supplying lower Egypt with about 20 million m^3. water per day for 100 days a year; 2 millions to be lost by evaporation, 5 millions to flow out to the sea, and 13 millions/day available for irrigation.

3. Wadi El-Raiyan could have created as a new province of Egypt and supplied it with irrigation during the flood season. «To do this will cost L.E. 418,000 and the work will occupy 2 years after which there would be an area available for cultivation of 86,189 feddans, i.e. a rate of nearly L.E. 5 a feddan», Liernur *et al.* (1888).

4. The Faiyum Province received its water through Bahr Yusuf Canal that took its water from Ibrahimiah Canal at a point some 270 km. south of the Faiyum province. The latter could be supplied directly from the new reservoir and the Bahr Yusuf water might be utilized in Assiut and Miniah Provinces (370 and 220 km. south of Cairo respectively). Also, the volume of water used in the Faiyum might, at the same time, be raised by 2 million m^3 water per day which render cultivable much richer land that only requires water.

5. In Gizah Province (facing Cairo West of the Nile) there were about 140,000 feddans of cultivable land that could be irrigated from the reservoir.

The above project did not materialize because it was found that the construction of the High Dam was more profitable to the country than the utilization of Wadi El-Raiyan as flood water reservoir. The High Dam is not only used as flood water storage but also as a greater source of hydro-electric power.

WADI EL-RAIYAN : A DRAINAGE WATER RESERVOIR

Birket[1] Qarûn (Qarûn Lake = 200 km^2 or 50,000 feddans, R.L. -45 m., see Fig. 2) is the natural place for the accumulation of the drainage water of El-Faiyum Province (387,000 feddans). The volume of the lake is about 678 million m^3 and it receives annually about 365.2 million m^3 drainage water from El-Faiyum lands, irrigated with «about 1,900 million m^3 water a year, i.e. about 5000 m^3 water per feddan», Ball (1939).

Evaporation (see Table 1) is the only effective factor that decreases the amount of water in the lake (about 400 million m^3 per year, El-Shinawy, 1966). If more drainage water will accumulate in the lake, its water level will rise above its normal standard and may inundate the near cultivable lands causing their damage. Accordingly, the water level of Qarun Lake is a major factor that limits the following :

1. Amount of irrigation water flowing from the Nile to El-Faiyum Province.
2. Areas and varieties of crops cultivable in the Province.
3. Construction of new drainage system in the province.
4. Area of new reclaimed land in the province.
5. Use of excess water of the High Dam as in the case of the other provinces in Egypt that benefit greatly from the High Dam water.

Consequently, the water level in Qarûn Lake causes the non-development or, even, the retardation of El-Faiyum Province and hinders its economic flourishing.

Different projects were studied to overcome the problem of drainage in El-Faiyum Province. These include :

1. Construction of an embankment around Qarûn Lake to allow the increase in the level of its water with more drainage water without flooding the near land, this project was rejected as it would only postpone the problem.

2. Mixing the excess drainage water with irrigation water and re-use it in irrigation, this was also rejected as the mixed water might increase the salinity and alkalinity of the cultivable soil of the province.

(1) Birket = an Arabic word for lake.

3. Utilization of Wadi El-Raiyan Depression (R.L. -60 m.) as a drainage reservoir for the drainage water that exceeds the capacity of Qarûn Lake. This project was found to be a most suitable solution for the problem of drainage in El-Faiyum Province.

The plan of the project is to construct an uncovered canal, 9.5 km. long from the southwestern edge of El-Faiyum till the desert border. Then the drainage water will flow through a tunnel (8 km. long and 3 m. diameter, i.e. 12 m^3 drainage water per second) to Wadi El-Raiyan at Hattiet El-Bagarat area (R.L. -10 m.), see Figs. 2 and 3. «The project will be finished within 4 years (1968-1972) and it will cost about 4 million Egyptian pounds», El-Shinnawy (1966).

The drainage water of 120,000 feddans (about 200 million m^3 a year) will drain to Wadi El-Raiyan Depression. As a surface area of water of 190 km^2 is enough to evaporate more than 200 million m^3 water a year, this area is attained at contour -13 m. in Wadi El-Raiyan (El-Shinnawy. 1966).

Advantages of the Project :

In the report of the Ministry of Irrigation of Egypt (1970) the following advantages are mentioned :

1. Drainage of El-Faiyum cultivated land, will be easier,
2. It will facilitate the supply of optimum water requirement to the cultivated lands of El-Faiyum (about 1090 m^3 more water a year for each feddan) and thus increase the annual crop yield,
3. Cultivation of an area of about 32,000 feddans, cultivable land that is not at present cultivated for the shortage of irrigation water and drainage system,
4. Encourage the reclamation of about 27,000 feddans and construct new drainage system to cultivate them in future,
5. Extension of rice cultivation in El-Faiyum to 40,000 feddans (nowadays, only 10,000 feddans are cultivated with rice),
6. Cultivation of about 20,000 feddans *Cyperus alopecuroides* (Samar Helw) for making mats.

DISCUSSION AND CONCLUSIONS

The main problem associated with the utilization of Wadi El-Raiyan Depression as a water reservoir either for flood water (up to R.L. + 30 m.) or drainage water (up to R.L. -13 m.) was the probability of water infiltration from the depression into the adjacent strata through porous rocks and/or fault planes ; this might be disastrous to El-Faiyum Province.

Before discussing this problem, we may refer to the process of water seepage from Qarûn Lake and try to find out the interrelationships between water infiltration out of the lake and the depression.

Ibrahim (1968) mentioned that Herodotus (450 B.C.) was the first to write about water seepage from Moeris (ancient name of Qarûn) Lake. Beadnel (1905), Ball (1939), Ibrahim (1968), and many others suggested that water of Qarûn Lake (R.L. -45 m.) percolated to Wadi El-Raiyan Depression (R.L. -60 m.). Beadnell (1905) argues (p. 23) that «It does not however follow that there was no leakage through the ridge into the Raiyan basin». Ball (1939) states (p. 288) «The great part of underground drainage from the lake have percolated into the neighbouring depression of the Wadi El-Raiyan and have been there evaporated almost as fast as it entered». Ibrahim (1968) writes (p. 47) « Water infiltration from Qarûn Lake to Wadi El-Raiyan is a definite fact as Wadi El-Raiyan is the near-most depression to receive water leaking from the lake». Willcocks (1904) explained that water infiltration from Qarûn Lake to Wadi El-Raiyan is not serious and if there had been any serious infiltration from the ancient Lake Moeris into the Wadi El-Raiyan there would have resulted a considerable lake which could not have escaped the notice of numerous travellers and writers who visited and described Lake Moeris. Ball (1939), confirming the infiltration of water out from Qarûn Lake and showing that about 87% of salt entered it from 250 B.C. to 1906 immigrated out of it by infiltration, writes (p. 288) «.... the infiltration may not have completely ceased until about the year 1890 when the surface of the lake first fell to a level of more than R.L. -44 m. for it is conceivable that the lake may have been brought into hydraulic equilibrium with the great underground

water sheet...». But Ibrahim (1968) rejected this opinion strongly and states (p. 49) «It is unbelievable to say that the water infiltration from Qarûn Lake, that continued for 3500 years, may stop suddenly in 1890». He added «... the communication between the lake and the depression is still existing». He describes the reason of dryness of Wadi El-Raiyan floor by the *Hydraulic Equilibrium* between the lake and the depression. The amount of water leaking out from Qarûn Lake equals the amount of water evaporating from the bottom of Wadi El-Raiyan. The weight of evidence seems to show that water seeps out of Qarûn Lake towards Wadi El-Raiyan.

On the other hand, water seepage from Wadi El-Raiyan was studied by many writers. Schweinfurth (1886) supposed that the freshness of Qarûn Lakes water is mainly due to the existence of subterranean outlet which may also exist in Wadi El-Raiyan. Beadnell (1905) states (p. 24). «Even if it was proved that there was never been leakage from Lake Moeris into Wadi El-Raiyan, it would not be safe to assume that the converse would not happen as the dip of beds is from south to north...». He adds «Judging from the nature of the Eocene beds forming Wadi El-Raiyan, my opinion is that leakage on a large scale would not take place and that owing to northerly dip, any water that escape from the reservoir would pass indefinitely northward and would not find its way through the overlying limestone to the surface in Faiyum cultivation. A detailed examination of the local geology would, however, be necessary to prove or disprove this». Accordingly, and depending upon his own geological studies, Ibrahim (1968) refused the idea of utilizing Wadi El-Raiyan Depression as flood (fresh) or drainage (saline) water reservoir assuming that «its water will infiltrate outside to El-Faiyum and damage its land and may cause swamping».

Attiah (1949) and Fox (1951) believed that Wadi El-Raiyan will be water-tight when filled with water depending upon the opinion of Beadnell (1905) who states (p. 24) «... in any case the agrillaceous (clayey) deposits would soon form a bed to all intents and purposes impermeable». Attiah (1949) mentioned that Wadi El-Raiyan might be regarded as water-tight for all practical purposes, and this was confirmed by Fox (1951) who states (p. VI) «... the underlying strata of Wadi El-Raiyan are known to be impervious.... This is my absolute assurance of the water tightness of the Wadi El-Raiyan basis as a storage reservoir».

Concerning the water flow from Wadi El-Raiyan Depression through the fault planes, Ibrahim states (p. 71). «It is not wise to neglect the serious effect of water flow through the fault planes as there are more than 26 fault planes in the area between Wadi El-Raiyan and El-Faiyum...». He adds «Calcification of fault planes is not an indication for their closing up (solidification), but the vugs in these calcite fault planes are widened by the continuous flow of water». Beadnell (1905) observed the presence of these fault planes and examined them and found that «the fault planes are mineralised with calcite without any trace of iron oxide staining». Fox (1951) proved by tests that the fault planes are solidified and will not allow for the water passage. He states (p. VIII). «After I had put down a pit on a fault plane, I did not find the breccicated rock even damp my confidence increased and I have became convinced that the Wadi El-Raiyan was a water-tight as could be established by human investigation...». He adds (p. 2). «In the southwestern area of Wadi El-Raiyan there are springs of good water which is believed to rise from the Nubian sandstone, 600 m. below. The springs are associated with faults of the same series. Since the springs emerge at R.L. + 20 m. to R.L. + 25 m. and not from faults veined with calcite in Wadi El-Raiyan at R.L. -30 m. it may be presumed that the fault planes are sealed».

El-Shinnawy (1966), depending upon the geological studies of Fox (1951), and his own knowledge and observations, and being the Minister of Irrigation then, gave the green light for the preparation of the project for the utilization of Wadi El-Raiyan as «*drainage water reservoir*» for El-Faiyum Province. He states «... the maximum level of the drainage water in the depression will be at R.L. -13 m. not at R.L. + 30 m. as it was proposed in the old project of Wadi El-Raiyan as flood water reservoir. This will make a difference of about 43 m. in level and thus water leakage, if there will be any, will not be serious problem». Accordingly, materialization of the project began in October 1968 and it is in use from January 1973.

ECOLOGICAL CONSEQUENCES

The utilization of Wadi El-Raiyan Depression as drainage water reservoir is not a simple matter but it may lead to ecological and environmental changes in the area. The following questions may be posed :

1. Will the storage of drainage water in the depression create certain swamps that are suitable for a life of mosquitoes or other disease transmitting insects?
2. The area around the depression is practically barren desert, what will be the environmental changes consequent to the filling of the depression with water?
3. The plant life in the depression is at present localized around the springs; what will happen in future when the whole bottom of the depression will be moistened? and which vegetation type will appear ?
4. Will this new lake cause climatic changes in the area?
5. Could the new lake be utilized for fish culture?
6. Experiments on *Juncus rigidus* proved that the plant (salt tolerant and fibrous) can be used as raw material for the production of good quality paper (Zahran *et al.*, 1972). One of the developmental projects of El-Faiyum province is to transplant large areas of land with *Juncus rigidus* and utilize its yield in paper industry. Could the Wadi El-Raiyan Depression be used to receive drainage water of a paper mill? Also, could we use the drainage water for irrigating *Juncus* plantation in the land nearer to the depression?
7. As Wadi El-Raiyan is located in calm, dry, sunny and fresh air desert, could we make use of its new lake and its high land as an attractive place for the tourists who are searching for relaxation, especially when we have seen that its mineral running springs are located at + 20 m. and + 24 m., i.e. far from the reach of the drainage water (R.L. -13 m.)?

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Fig. 1
Location Map of Wadi El Raiyan

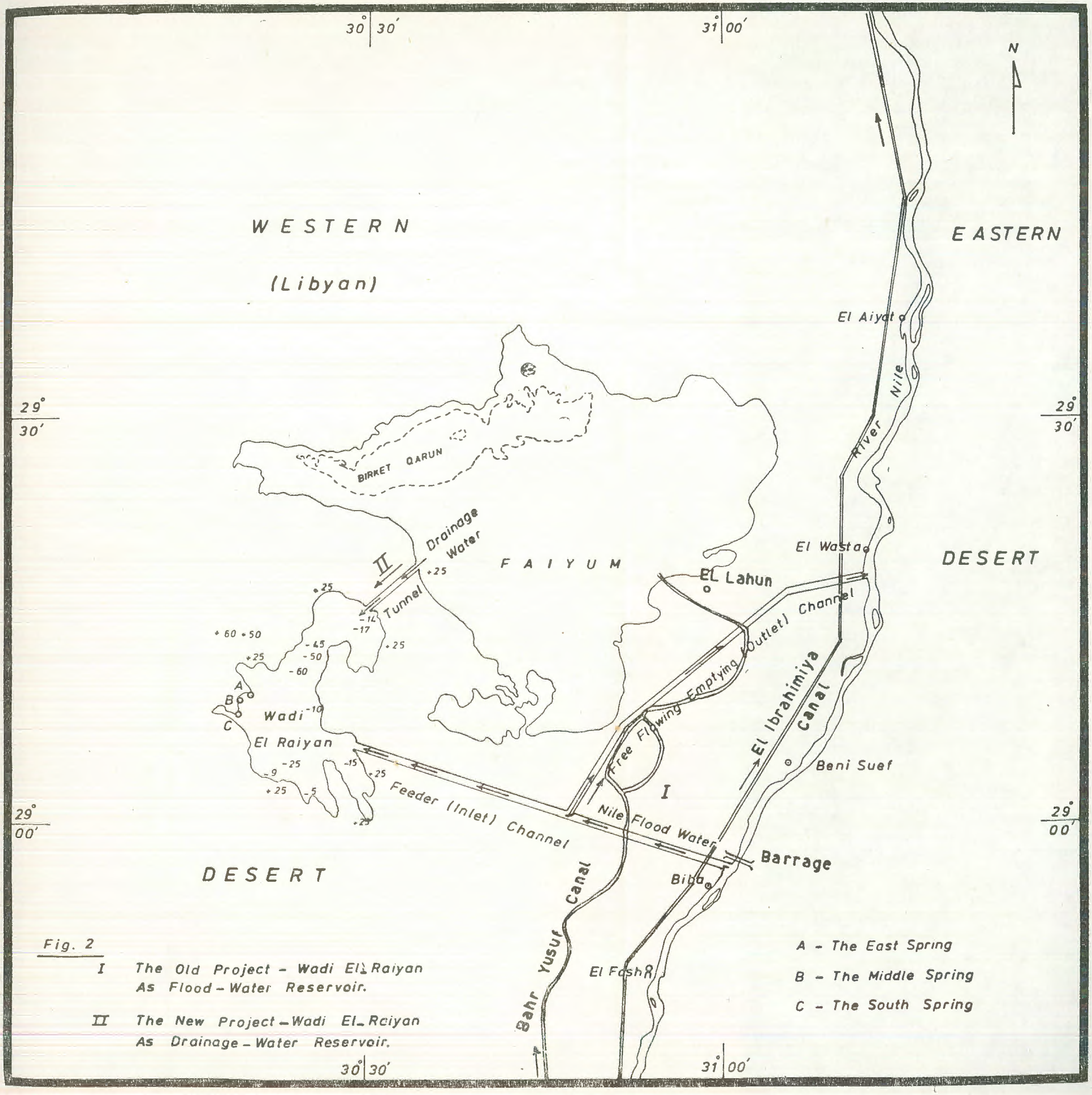

Fig. 2

I The Old Project - Wadi El-Raiyan As Flood-Water Reservoir.

II The New Project - Wadi El-Raiyan As Drainage-Water Reservoir.

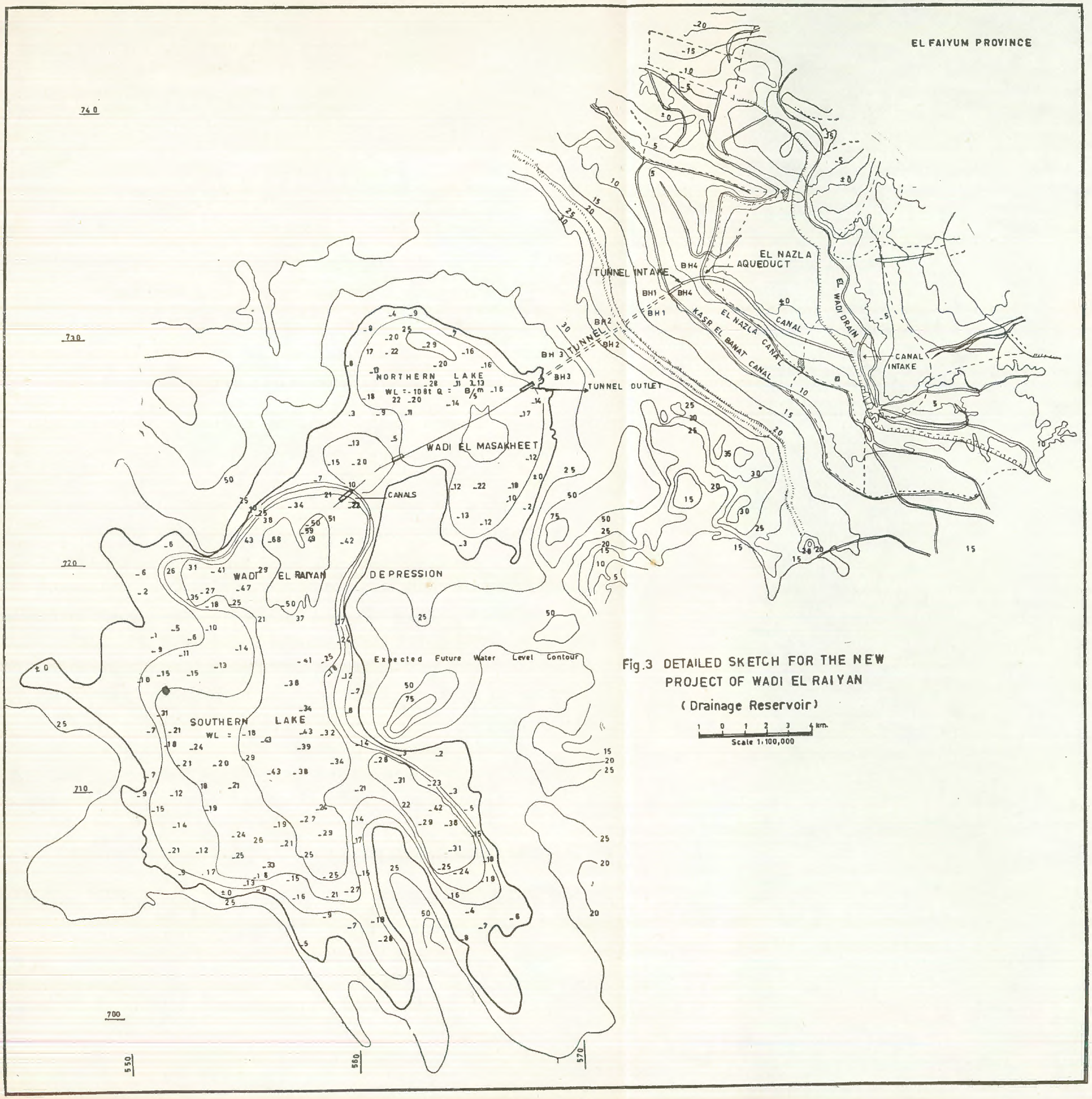

Fig.3 DETAILED SKETCH FOR THE NEW PROJECT OF WADI EL RAIYAN

(Drainage Reservoir)

SOME ASPECTS OF LABOUR MIGRATION IN WEST AFRICA

BY

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POPULATION STATISTICS

Like the other subregions of Africa, West Africa's demographic statistics are not adequate and reliable, especially as far as data are concerned. However each of the West African countries has taken one or two censuses after independence. Sometimes it was a sample survey to determine the total population or other demographic characteristics at different periods. But the major problems concerning our topic, is the non-availability of statistics on international migration which usually takes the form of over-land crossings from one country to another. The factors that justify a distinction between internal and external migration in more advanced areas have not been present in West Africa until recent. People migrate from northern Ghana to Kumasi or Accra for much the same reason as they do from Upper Volta [1]. When they reach their destination they have the similar cultural and linguistic problems. This is obvious where ethnic and cultural zones bear no relation to political boundaries.

LABOUR MIGRATIONS AS A COLONIAL PHENOMENON

Movements across land frontiers in West Africa, as in other parts of the continent, is a phenomenon which has been known to be going on

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(1) Caldwell, J.C.: Migration and urbanization, in A study of Contemporary Ghana, vol. II, 1967, ed. Birmingham et al., 1967, p. 111.

in the subregion for a long time. So, migrations both temporary and permanent are old stories. But *labour* migrations which have taken place in the second half of the nineteenth century and twentieth century, great as they have been are no such breaks with the past as it is sometimes suggested [1].

Since the beginning of European penetration into Africa, the undertakings that have established themselves there, had to draw their labour from some distance away from their centres of operations. It is also well known that the African population, leading nearly a subsistence life, showed no inclination to seek wage earning employment voluntarily. This led to introduction of compulsion systems of labour recruitment whose nature and development, are unnecessary to discuss here.

THE CONTINUATION OF LABOUR MIGRATION

Today, vast areas of Africa are free from European rule, but labour migration continues. So labour migration, which formerly had been an imposition upon the Africans, became an important part of their own sociocultural system. It becomes a general feature in West Africa to witness or hear about men or migrant workers who shuttle between home villages and employments. Governor Macdonall of Gambia recorded the migrant presence in Gambia as early as 1852. «It is a fact that at least one third of produce exported is raised by natives, who travel from distances of 500 and even 700 miles in the interior to visit the Gambia along the banks of which they live. Most of them remain for two or three years till they have earned the money sufficient to enable them to purchase goods» [2].

Albert Balima, deputy director general of labour and man-power in the Ministry of Social Affairs, Republic of Upper Volta states after

[1] Colson, E.: Migration in Africa, Trends and Possibilities, in Lorimer, Karp, Population in Africa, Report of a Seminar, Boston U.P., 1960, p. 60.

[2] Jarrett, R. : The strange farmers of Gambia, *Geographical Review*, XXXIX, No. 4, October 1949, p. 649.

independence «The most vital problem, and the one which the entire future of the nation depends on is that of migration. Every year the population increases by 2 per cent. Everyday thousands of citizens of the republic, believing that living conditions are better in rich lands to the south, in Ghana and the Ivory Coast, follow in the footsteps of earlier generations. There are believed to be somewhere between 300,000 and 400,000 emigrants in Ghana, and between 200,000 to 250,000 in the republic of Ivory Coast [1]. These two statements reveal that labour migration has been known since the European penetration and still to the present times.

MOTIVATIONS

The reasons why particular individuals desire to earn money vary greatly. From traders, settlers, missionaries some Africans have learned to know and desire the products of the civilized world. In 1899 Sir Harry Johnston was astonished when Ganda chiefs requested him to supply them with gramophones. He found the people of Buganda «greedy for cloth and almost every manufactured article» [2]. However, in different parts, the push and pull forces differ in their intensity and their relative importance. Whatever is to be said about the motives of labour migrations in West Africa, it may be summed in the economic, social and historical factors.

The historical factor made the first push for migration. People began to migrate for work to pay taxes. These taxes were diversified, i.e. poll tax, hut tax, all are introduced by colonial administrations. Skinner stated «The French in 1896, immediately after conquest demanded taxes in Francs rather than in coweries. Some tried to meet the new obligations by intensifying their dry season trade to the northern Niger zone, but since French conquest had largely destroyed the northern

[1] Skinner, E.: Labour migration among the Mossi of the Upper Volta, in Hilda Kuper, *ed.* Labour migration in West Africa, p. 61.

[2] Richards, A.T.: Economic development and cultural change, Heffer, 1964.

trade, they concentrated on the south. They soon found that working in the «Gold Coast» is more profitable than trade. The taxes were raised gradually and more Mossi men had to migrate for work [1].

If the historical factor was responsible for starting the process of labour wage earning, then today the economical factor that predominates. Even within the historical factor, the economic force is evident. The fact that in certain societies, migration is pattern of the social life is not inconsistent also with this view; our view is that underlying the various factors, there are important economic forces determining the magnitude of the labour migrations. It might be clear that for the areas where the farmers grow neither surplus food crops, nor an export crop, the main source of cash income will be in wage labour. But because these areas are economically so backward, local employment is scarce, except perhaps where the government decides to construct a highway or some other development projects.

Perhaps one of the most interesting problems in the human geography of the African countries is to estimate the carrying capacity of the land under traditional systems. What is the practical population densities at which emigration must start? One of these criteria might be soil exhaustion and human malnutrition. This is clear in most of the emigrant areas in West Africa. Good farm land is becoming more and more scarce, and a subsistence agriculture fails to satisfy the ambitious young generation. In Sierra Leone for instance, most upland areas need a fallow of eight to ten years to produce good rice crops, the staple food of the people, but actually the fallow is below five years with decreased yields, until it will no longer produce rice and has then been given over to the cultivation of Cassava [2]. This phenomenon of the soil depletion is repeated by many witnesses in some areas of West Africa. Skinner found in his study of the Mossi that nearly all whom he had questioned about the reason for emigration, emphasised the economic motive, «when one asks several persons why young men leave home to

[1] Skinner, E.: *op. cit.,* p. 63.

[2] Banton, M.: West African City, a study of tribal life in Freetown, Oxford U.P., 1957, p. 43.

work, the answers are similar, I am a poor man. I need money to pay taxes and to buy clothes and another may declare I want a bicycle and clothes for my wife» [1]. Let us suppose that a youth is able to gain money for the essential needs, in his homeland, then how would he save money for some special cases such as paying dowry, either in cash or in kind? This dowry ranges between 150 s to 300 s. To this factor and also for fulfilling household budget in the village would attribute the inhibition of the growth of a stable urbanised based community in West Africa [2]. This attitude of the African towards paid employment is therefore described more aptly as «buying money» than as earning money [3]. It is noteworthy also even in Ghana, how the westward spread of cocoa has affected migration patterns in the Eastern region. Emigration from the earlier developed eastern forests of Akwapim and south Abuakwa is counter balanced by net immigration in the western forests of the eastern region. Similarly for the same reasons, emigration from eastern Ashanti is counter balanced by net immigration in the forests of western Ashanti [4].

At the same time we find this phenomenon has increased since market crop production increased and towns have grown in commercial importance. This is noticed in West Africa with special reference to cocoa, groundnuts, coffee, to mining diamonds, iron ore, tin, bauxite, gold. The development of mining especially after the second world war, gives the mining areas the same attraction as the farms. The growth of towns in West Africa was more rapid than other parts of the continent. Available data shows that urban population in West Africa (towns and cities with a population of 200,000 and more) formed about 12.4% of the total population around 1960. This compares with about 5% of Eastern

[1] Skinner, E.: *op. cit.,* p. 66.

[2] Wood, E.: The implication of migrant labour for urban social systems in Africa, *Cahiers d'études Africaines,* vol. VIII, 29, p. 13.

[3] Mason, P.: Inter-territorial migrations of Africa south of the Sahara, Report in the *Inter. L. Rev.* XXXVI, No. 3, September, 1957, p. 294.

[4] Hunter, J.M.: Regional pattern of population growth in Ghana, 1948-1960, in Essays in Geography for Austin Miller, *ed.* Whitrow, Wood, Reading U.P., 1965, p. 281.

Africa and 13% for the whole of the continent [1]. These figures indicate that the rate of urbanization is quite high in West Africa. This high degree of urbanization is not due to the town's social function exclusively, but also to its economic and administrative ones. Many of these towns are the principal ports, which were selected as colonial capitals and continued this function after independence. To have an idea about the development of these ports, Hilling stated that in the short period since 1946 the tonnage handled annually by West African ports has increased dramatically from 7 million to over 75 million tons [2]. So the demands of European firms and administration for African employees, created a special drift to these towns.

Before leaving the economic factor we may stress that in many emigration areas, it is not necessarily malnutrition and poverty which prevail. Sometimes the able-bodied male availed himself for the opportunity of raising his standard of living.

To sum up the economic factor, we may say that the international movements for wage labourers reflect differences of progress, the relatively highly developed territories, absorbing man power that does not find sufficient opportunities for wage earning employment in its own territory. This will be revealed clearly when we study the per capita income and the degree of industrialization in the countries of West Africa.

If we turn to social motivations, we have two points of view about its importance as a determinant factor of push. It is a chance to compare east and south Africa with west Africa concerning this factor. Winter in his study of the Emba stated that most of the men who left their lands, claimed social disturbances and family quarrels. Sometimes if there is a quarrel between two brothers, or with a neighbour, the solution a man finds is either to leave on his own or with his family. If a man feels that his neighbour is practicing black magic upon him, he has to remove and seek other work in other place [3]. Shapera and other anthropologists

(1) E.C.A., *Economic Bulletin for Africa,* July 1966, p. 91.

(2) Hilling, D. : The Evolution of the major ports of West Africa, *Geographical Journal,* 135, September 1969, p. 377.

(3) Winter, E.H. : The Bwamba economy, East African Study Series, No. 5, Kampala, 1955, p. 38.

stated that labour migration became one of the important rites of the tribes [1]. The youths are not suitable for marriage if they do not spend certain period abroad. That means that migration became a cultural requirement. At the same time there is the youth who feels that traditional tribal life and obligations are nothing but a heavy burden on his shoulder, so he might escape them if he migrates.

If we wish to apply the social motives to west Africa, we will find that it is applicable here but not as a dominant factor. The young men migrating to Freetown stressed that the foremost treason for coming was that money was so easily obtained there, and that so many fine things could be bought with it, secondly in Freetown they are free [2]. Although Skinner stated that none mentioned that he had gone for any reason except the economic, but the social factor appeared when a number of men stated that they were going to the «gold coast» because they had stolen women from their husbands. Others fled after being accused of theft or rape or after being caught in the act of adultery. But none stated that he migrated because he had quarrelled with his chief. Anyhow it was the Mossi women rather than the men who ran to neighbouring territories because of dissatisfaction with an arranged marriage, especially with old husbands. Wife stealing is indeed one of the main problems in Mossi country. It accounts for about 99% of all cases tried in court [3].

The demand for the city or the town for its innovation and forms of excitement must not be ignored at all because there is a growing acceptance of town as «a way of life», an appeal to the wider cultural horizons of young people. Others desire to get fresh experiences. The Mende of Sierra Leone have a saying «A person who has not travelled thinks that only rice cooked by his mother is sweet», and a song popular in the French territories bordering Ghana, «Qui n'a pas été à Kumasi, ne va pas au Paradis» [4]. These two statements sum up the lure of the

(1) Shapera, I. : Migrant labour and tribal life, p. 115.

(2) Banton, M. : *op. cit.,* p. 36.

(3) Skinner, E. : *op. cit.,* p. 66.

(4) Little, K. : West African urbanisation as a Social process, *Cahier d'études Africaines,* No. 3, October, 1960.

town. Gregory in his study of migration in the Upper Volta ascertained the rural urban flow of migrations; 60% of all moves in urban areas. After the first move, however, the urban-urban component dominates. A great deal of movements from town or city to another is observed, with rural-urban and urban-urban components of migration, taken together, ranging from 73% to 93% of the total movements depending on the move [(1)].

But what about the people themselves who migrate seeking wages and employment? It seems that the famous migrating communities for wage earning in west Africa had been on the move for a long time, not necessarily as labourers but as traders. It is already evident that west Africa has probably the largest record in sub-Saharan Africa of commercial contacts with Europe and the Mediterranean, long before the fifteenth century. It was not a stagnant region at all. Gold especially at the Wanagra, slaves, ivory, ostrich feathers and hides moved northwards across the Sahara in return for salt and a number of luxury items from north Africa. While southwards came in return not only the products of the Savannah land, but also beads, salts, cowerie shells — goods which had been traded across the Sahara [(2)]. Although the Mossi activities included the cultivation of several varieties of millet, and sorghum besides some vegetables, they also herded livestock, which they traded with grain to Timbuktu in the north and the forest zones of Ashanti and Togoland. The early Mossi traders were well known around Timbuktu as men who did not waste their money, but who departed as soon as their business was concluded. So is the case with the Hausa and Yoruba who were trading to and from Ghana for a long time. Most of the Kola trade has been carried out by Hausa dealers [(3)]. While its major centres of consumption are in the Savannah, the Kola is grown only

(1) Jeal Gregory : Migration in the Upper Volta, in *Urban African Notes,* African Studies Center, Michigan University, vol. VI, No. 1, Spring 1971, pp. 47-49.

(2) Oliver, R., Fage, J.D. : A short history of Africa, 1966, pp. 102-112.

(3) Cohen, E. : Politics of Kola trade, in Whitham, E., Currie, J., Readings in the applied economics of Africa, vol. I, Cambridge, 1967, p. 153.

in the forest zone, where the necessary climatic conditions prevail. In the same time the Hausa has nearly monopolised cattle trade from the north. Floyd also describes the Ibo as people with a great commercial bent. Their enthusiasm and success as traders have carried them to the four corners of Nigeria, and they have been likened to the Scots in their canny financial transactions and ability to turn the penny-penny in their direction [(1)].

REGIONS OF EXPORTS AND IMPORTS

While all countries of west Africa, or even most of the continent is considered by economists as under-developed compared with those of North America and Europe [(2)], there are great variations in the present level of economic development between the various countries of west Africa. The following table shows the difference in per capita income in 1967.

TABLE I

Gross national product per head in West Africa in US $ for 1967 [(3)]

Ivory Coast	230	Gambia	90
Ghana	200	Nigeria	80
Liberia	190	Dahomey	80
Senegal	190	Niger	70
Sierra Leone	140	Mali	80
Togo	100	Upper Volta	50
Guinea	90		

(1) Floyd, B. : Eastern Nigeria, A Geographical Review, London, 1969, p. 30.

(2) See the criteria for developed and under-developed in : Phyllis Deane : The long term trends in world economic growth, in Gerald, M., *ed.* Leading issues in economic development, Oxford U.P., 1971, pp. 10-29; James Lamb, Rich world, poor world, London 1967, pp. 11, 26.

(3) Seers, D., Joy, L. : Development in a divided world, Pelican 1971, pp. 67, 69.

While no west African country, yet has an economy dominated by manufacturing, there are great differences in the extent of (relatively) industrialization, as reflected in the energy consumption which shows that Ghana, Ivory Coast and Senegal have the most kg. per capita coal equivalent in west Africa (+ 400), also Nigeria and Dahomey (30-60). Then Togo, Mali, Niger, Upper Volta represent the other extreme (30) in 1967 [1].

It is noticed that the countries of imports for man labour are the wealthiest countries and the most industrialized, while the export countries are the poorest and less industrialized. This supports the view that the economic motivation plays the dominant role, as mentioned above. The regions of *export* are mainly related bioclimatically to the sudanic proper with one rainy season of approximately two and a half to 5 months. Rainfall begins generally in May and ends in October. Annual rainfall totals vary between averages of 20 inches in the north and 32 inches in the south. As totals are less significant in agricultural practice, then variations may give us a more accurate idea. It is noticed within this region that deviation may be over 30%, and even in years of sufficient rainfall total, rains may fail at planting time. The other remarkable feature of the dry season in west Africa, except the Guinea coast, is its extreme dryness. This is why Skinner described the Upper Volta in the dry season, «during the dry season, Mossi country presents a picture of such utter aridity that one wonders whether it is possible for such parched red soils to produce plant life» [2]. The potential evapotranspiration over the year exceeds rainfall. Therefore the growing season tends to end as soon as precipitation falls below the rate of moisture loss. It is a great problem for a cultivator to retain a seed reserve against the possible need for a second sowing [3]. A single growing

(1) O'Cooner, A. : The geography of tropical development, Pergamon, 1971, pp. 16, 17.

(2) Skinner, E. : The Mossi of the Upper Volta, the political development of a Sudanese people, Stanford, 1964, p. 3.

(3) White, H.P., Gleave, M.B. : An economic geography of West Africa, London, 1971, pp. 19, 20.

season followed by a large rest period has meant a great dependence on food storage. Perhaps the greatest problem is that most of these lands are within the land-locked states, so they are far from the coast and the ports. So some try to find a cause of labour migrations from these inland states; that the prices they can get for groundnuts grown in their homeland are considerably lower than they would be near the coast. This means that working outside their lands is more profitable [1].

This is a general picture about the habitat. If we look on the distribution and densities of population, we find the two extremes together. On the one hand it is 97 persons per Km. in the Upper Volta, the land of the famous migratory labourers and on the other hand it is 258 in Nigeria and reaches more than 1500 in the Ibo heartland. At the same time it is 62 in Senegal, 60 in Sierra Leone and 142 in Ghana as recipient regions [2]. These figures may give an idea that migration does not depend utterly on density differentials, as a wind blowing from high pressure to low pressure, but it is due to the desire of finding a more profitable work.

Upper Volta is considered one of the poorest members of the Conseil de l'Entente. In 1966 the state exported only $ 16 m. worth of commodities. Her imports were worth $ 28 m. Much of the republic revenue comes from the seasonal or long term Mossi emigrants. There is nothing Upper Volta could produce which other territories could not produce more cheaply. To some extent it is true for Niger with a low per capita income and a continuous deficit of trade ($ 10 m.) in 1966 and its remoteness from the seaboard (800 miles), though the southern districts benefit from the proximity of the groundnut markets of northern Nigeria. It is also true of Mali which is nearer to Niger (per capita income $ 80) and had a deficit in the balance of trade of $ 23 m. in 1966. Its chief economic and political problems are derived from a poorly edowed environment besides her land-locked position.

(1) Berry : *op. cit.*, p. 41.

(2) E.C.A. : *Economic Bulletin for Africa*, July 1966, p. 89.

TABLE II

West African International Trade by value of M. in 1966 (1)

	Exports F.O.B.	Imports C.I.F.
Ivory Coast	310	257
Dahomey	11	34
Gambia	14	16
Ghana	244	352
Guinea	58	53
Upper Volta	16	28
Mali	13	36
Niger	35	45
Nigeria	792	718
Senegal	149	161
Sierra Leone	83	100
Togo	86	47
Liberia	151	114

Geographically and economically there is little difference between Dahomey and Togo. The per capita income is nearly the same. They share also the problem of elongation, small size besides poverty, though Dahomey has a deficit in the balance of trade.

Though the same causes may be applied to the coastal migrations, there are other factors than severe poverty. Togolese and Nigerian immigrants in Ghana made up 57% of all immigrants recorded at the 1960 census in terms of foreign origin. They leave their homeland because they could earn more money in Ghana. Togo also has a common border with Ghana, and the political boundary cuts the land of the Ewe tribe into two. The explanation of the Nigerian stream is that the southern part of Nigeria has really the densiest population in west Africa, but a part of the explanation lies also in the fact that Nigeria is the nearest ex-British

(1) United Nations : Statistical Year Book, 1967, New York, 1968.

colony to Ghana, and from this common history stem various similarities in administration and official language (1). This led the migrant to feel that he would not be in a completely foreign environment. It was found that the Togolese were restricted to Ewes from southern Togo, and the Nigerians to those born in the Eastern and Western regions.

The regions of *imports* are the southern countries which border the ocean, especially those which have high per capita income (Ghana, Ivory Coast, Senegal) besides Gambia though it is not in the same economic category.

Importation of labour may be attributed to many factors: first it occupies areas included within bioclimatically either the Guinea proper or the Sudanic. The Guinea proper has two rainy seasons totalying approximately 9 to 12 months and air of high relative humidity through most of the dry season. The sub-Sudanic includes Gambia and the southern half of the Senegal with one rainy season from five to seven months. What I mean here, that these regions do not suffer from a long dry season as happens with the northen regions. Second, these are places that witnessed the European interest because the coast was the first step to the interior. So it had the most interest and investments i.e., cash crops and transport development earlier than the interior. It is enough to say that the railway to Ougadougou was not extended till 1954. Third, this is the region of cities and towns especially ports.

So, these states, especially the relatively developed either through cash crops or mining had a magnetic attraction for the less developed people's countries.

Ghana, one of the wealthiest countries of West Africa, had an estimated income in 1967 of over $ 200 per head. From a study survey of 1963 for the migrants reaching Ghana, 86% went first to towns, 4% went to the mines and 10% to the cocoa growing areas. But those who remained in towns are no more than the third. In many cases, the towns are the obvious stopping points en route to new employment in southern Ghana, whether in the cocoa farms, or in urban service activities.

(1) Caldwell, J.C. : *op. cit.*, p. 115.

The Ivory Coast with its cocoa and coffee and timber shares with Ghana half the imported labour in west Africa. It tries to industrialize its economy and may be considered one of the industrialized countries of west Africa. It has not witnessed any deficit in the balance of trade through the 15 preceding years.

Senegal has its production of groundnuts and industrial Dakar, the port of much of the western Sudan and also the federal capital for French West Africa.

Gambia though it is poorly endowed with natural resources, but it's lower duties compared with Senegal, has an excellent river route in one of the most productive of the groundnut-growing sectors, which attracts labour from Senegal despite the latter's prosperity.

Fernando Po with its plantations of cocoa has attracted a significant labour force mainly from eastern Nigeria. In 1961 after a negotiation between Nigeria and Spain their wages were doubled and the pass system controlling their movements was abolished [1].

The Southern Cameroon appear to be a resort of the lesser educated and those whose economic resources were insufficient to enable them to enter the more popular, but highly competitive life of migration to Nigerian towns. The bulk of the southern Cameroon immigrants come from two heavily peopled areas of Eastern Nigeria [2]. The employment of the Nigerians is primarily due to failure of the southern Cameroon to supply enough bulk labour.

AXES OF MOVEMENTS AND ROUTES

After having seen the regions of exports and imports of labourers, we have to discuss the link or the strains between the two regions. But before, we must have in mind that the situation in west Africa is rather different than that in southern Africa, where there are European-owned

[1] Morgan, W. Pugh J.C. : West Africa, London, 1969, p. 721.

[2] Ardner, E., Ardner, S., Warmington, W.A. : Plantation and village in the Cameroon, some economic and social studies, Oxford U.P., 1960, p. 198.

mines of the Rand. There have been important economic developments of a wide range of cash crops, but generally the production units have been small, and have not had the same need for organized labour such as is required in large scale enterprises. West Africa has never been attractive to European settlers for climatic and disease reasons. Mining has been developed in some states, but nevertheless there are no special agreements between the export and import states about the numbers and arrangements of labourers as the case between Mozambique and South Africa. The only exception is the agreement between Nigeria and Spain concerning labour for Fernando Po.

So the movements have been less organized than on the southern part of the continent, and since they are free and more spontaneous there is a lack of information about them, concerning the exact numbers, the routes, the means of transport. But what we can say that in certain measure much of west Africa forms a big market where changes in wages or job opportunities, or changes in the prices of crops commonly cultivated under share-cropping arrangements, affect the size and the direction of labour flows. Thus changes in the prices of peanuts in Senegal could have some effects on the supply of labour in the Ivory Coast, as Mali migrants have customarily gone to both places. And changes in wages or job opportunities in Ghana influence the flow of Voltaics to the Ivory Coast, for Ghana and the Ivory Coast are alternative destinations for migrants from the Volta republic. We can add also the new regulations and procedures concerning aliens after independence. Nevertheless, it has been stated that by and large, African migrants cross territorial frontiers with little or no supervision. This is true despite the large body of relevant legislation, since an effective border control is physically impossible in most of Africa.

But we can say that though labour migration is a colonial heritage, yet the routes and the destination of migrants display in many instances the pre-existence of pre-European patterns. Three fairly distinct migratory trends of labour are discernible. The largest stream runs along a *north-south* axis, from some of the northern parts (Upper Volta, Niger, Mali) to Ghana and Ivory Coast, from the Sudanese belt to the coastal areas. Another small stream flows from the Niger and eastern Upper

Volta to Nigeria, Dahomey and Togo. Although the north-south streams have not been fully studied, Berg thought the number was nearly one million a year [1], about half of them in Ghana and Ivory Coast, and they are chiefly from the Mossi and Gourunsi tribes. The routes they use are the same used by traders; from Ougadougou and points north, the migrant went through Ougadougou and Po, or through Koudougou and Leo to Ghana. From points south, they went straight down through Po or Leo, and from points east they moved through Tankodog crossing the Ghana border at Bawku. Skinner [2] stated three reasons for the Mossi and Gourunsi, who represent most of the migrants moving in the north-south direction for preferring Ghana. The Mossi has ancestral links with Gambaga and most of their traditional trade was with such market towns as Salaga in Ghana; the British paid their workers adequate salaries, whereas the French did not; moreover, very often the French did not even try to attract labourers with wages, but resorted to the (corvee) or forced labour.

The *east-west* axis migration is divided into inland and coastal. The inland or as it is called western migrations, varies in numbers, or fluctuate markedly with the fortunes of peanut crop, and according to the news received in different parts of the coastal area, because this move starts mainly from Mali, the western parts of Senegal and north western parts of Guinea to Senegal and Gambia. They are known as «Nevetana» in Senegal and the strange farmers in Gambia. This east-west movement involves 75,000 men according to Berg, while Thompson and Adolf increased them to 150,000 annually [3]. Not all the movements that come from the east go to rural areas, but some of the migrants go to urban and mining regions, as those who migrate to the diamond fields in Sierra Leone, or the Tekrour who moves to Dakar. The first is estimated roughly between 15,000 and 21,000, as the British authorities had

[1] Berg, E. : The economics of the migrant labour system, in Hilda Kuper, *op. cit.*, p. 61.

[2] Skinner, E. : Labour migration and its relationship to socio-cultural change in Mossi society, *Africa,* 30, 1960, p. 378.

[3] Thompson, U., Adolf, R. : French West Africa, 1958, p. 493.

evicted a number nearer to the one mentioned in 1956-1957 [1]. Most of them settled in Guinea. The east-west coastal migrants, mostly from southern Nigeria, Togo, Dahomey are attracted by the jobs found in southern Ghana. They are the model of people who migrate because of the higher incomes they could earn in Ghana and the Ivory Coast. At the time of 1960 census the population in southern Ghana which had not been born there consisted of 314,000 persons from the coastal countries plus 189,000 from southern countries. Thus it is estimated that the coastal migrations share is about 50% of the total foreign and northern immigrants [2].

A minor coastal route or routes may be mentioned here, one from the Nigerian coast to Fernando Po, the other extends to the Cameroon coast. The latest route has been running for a long time according to the so called (gari contracting) by Efik Ibibio who brought Ibo migrants by canoes from Calabar, and who only received payment from their passengers if employed. Each migrant when employed paid the contractor 7 s at a time when wages in cash and kind were 7 s per day [3]. Concerning the inland routes and how the labourers use them, it is known that they proceed on foot if they have no money and this is almost the case. He may participate in any job on the way to get funds for transportation. But to go all the way on foot is an old story after the diversification of methods of travel nowadays. The distance from Sokoto town to Accra, if it is made on foot at an average distance of 20 miles per day, is 35 days [4]. So they go part of the distance, if not all, by some means of transport. It appears that lorries are the most used, because they are the cheapest, besides the migrants are some times fortunate to meet drivers at the border towns who are commissioned by Ashanti cocoa farmers to procure labourers and give them free transportation. Some firms pay transport for the labourer and where appropriate, for his family as a way of stabilizing

[1] *Ibid.,* p. 394.

[2] Caldwell, J.C. : *op. cit.*

[3] Ardner, E., et al. : *op. cit.,* p. 198.

[4] Prothero, M.R. : Migratory labour from North Western Nigeria, *Africa,* vol. XXVI, July 1957, p. 256.

employment [1]. So proximity to a main road may be of some significance. Swindell states that over half of the Marampa (iron ore mines in Sierra Leone) labour force comes from settlements located on a main motor road, along which there is reasonably regular movement of lorry traffic [2].

TYPES OF MIGRATIONS

Migrations are divided according to the time spent out of the home country to : seasonal migrations in which most of the males get out for four to six months; seasonal migrations in which the labourers are absent for one to two or three years and then return. The migrant in this category is called a target labourer, because he returns back as soon as he has achieved his goal, namely a specific sum of money; permanent migrations when all the family moves and settles in towns or other agricultural projects. Then where can we put the west African labourer? Most of the west African labourers lie within the short and seasonal categories [3]. Within these two types we can put most migrants who come from the interior to work in cocoa and coffee farms of Ghana, Upper Volta, Fernando Po, Cameroon, Senegal and Gambia. We may add also those who join work in mining areas. The minority who have permanent migrations, most of them work in towns as clerks, policemen or craftsmen, although most of them hope to return eventually. In the case of the short term and seasonal migrations, the unpublished result of a study by Berg revealed a high proportion of seasonal migrants in the north-south direction, from the Upper Volta, Niger to Ghana and Ivory Coast. From a sample of 195 men returning north from employment in the Ivory Coast, about 45% claimed to have been in employment six months or less, and slightly under 40% between six months and a year, only about 7% said they had been in employment for more than two years [4].

(1) JURGENS, H.W., TRACEY, K. MITCHELL, P. : Internal migration in Liberia, *Bulletin Journal Sierra Leone Geographical Association,* No. 10, 1966, p. 47.

(2) SWINDELL, K. : Origins of the Marampa force, in J. CLARKE, *ed.* Sierra Leone in maps, University of London Press, 1966, p. 98.

(3) CALDWELL : *op. cit.,* p. 111.

(4) BERG : *op. cit.,* p. 166.

While Skinner stated that the Mossi migrants, more so than any other groups tend to remain in Ghana for two to three years. On the tin-rich Jos plateau, where the ore is still dug from open cast mines by hundreds of men and women with shovels and head pans, many workers come for only two or three weeks, and the supply of them, strangely remains sufficient through the year [1]. This means that there is a cycle of employment. Ampene also stated that those labourers who come from the Upper Volta and other neighbouring states are the most transitory group coming to the Obuasi gold field. It is only by ingenious devices that the mining authorities persuade some of them to stay for at least five years. The migrant labourer from the north would prefer to go back before the rains begin in April and make a farm for his family and dependents [2]. To encourage such men to stay, the company does not employ anyone who has been in employment with it for more than three occasions. Many firms also try to induce workers who have proved satisfactory to return to them season after season by adding to the stipulated wages presents of money or clothing or both when the labourers leave [3].

In most cases we find temporary migrations coincide with the dry season, though some migrants go abroad during the wet season. But this is the exception to the rule. Several features of the physical and economic environment make temporary migration suitable in the dry season. In the Sudanic or savannah zone, men are underemployed during the dry season. In the forest or coastal zone where conditions are favourable to the growth of export crops such as coffee, cocoa and rubber, owing to the abundant rainfall. So the climatic zones in west Africa are so ordered that the slack season in the savannah is the busy season along the southern coast. The season of inactivity in the savannah (which was occupied in war-fare and hunting before) corresponds to the time of peak agricultural demands in cocoa and coffee regions. Then this is a natural adaptation between the two climatic and economic zones. So the temporary labourer

(1) LLOYD, P.C.

(2) AMPENE, E. : Obuasi and its miners, *Ghana Journal of Sociology,* vol. 3, No. 2, October 1967, p. 76.

(3) INTERNATIONAL LABOUR OFFICE : African labour survey, Geneva, 1958, p. 58.

makes benefits of cultivating his own land and working abroad. He should not move for work abroad until the end of November, when his own growing season comes to an end, and all his crops have been harvested. They should remain in Ghana for about five months. When the flowering of certain trees shows that the rains are approaching, the migrant should collect his seasonal wages, and without delay after buying his needs, goes along the road home. Nevertheless some men tend to stay more than others for two reasons : 1) Before he leaves he attempts to make as much money as possible so that he will be able to remain at home for a longer period, 2) the customs tolls which the returning migrant must pay on the goods he brings back are so high that the exorbitant tolls contribute to the extended time being abroad [1].

This is the case with the north-south axis of migration. In northern Nigeria they call this type (Masu cin rani) men who will eat away the dry season. They are also called «yan tuma da gora» — sons jumping with a gourd because they carry a gourd for drinking water [2].

The other group who migrate in the dry season for temporary work are represented by those who go to towns. Banton stated that the numbers of workers who were registered for employment in Freetown in January had been higher than any other time of the year [3]. It may be that they realise that January is the beginning of the financial year and the prospects for work are good. But what support the other view that migration to Freetown fell away after February then dropping sharply with the onset of heavy rains.

The only migration in the wet season is the east-west one, which goes from Mali, Niger, Upper Volta to Senegal and Gambia. This is because both the country of origin and the country of destination are within the same bioclimatic zone. So the strange farmer has in Makinde language another name «Sama Manila» literally rains abroad because he begins to arrive in Gambia in March and until the end of June. A good strange

(1) Skinner, E. : Labour migration and its relationship ..., p. 382.
(2) Prothero, M.R. : *op. cit.*, pp. 253-254.
(3) Banton, M. : *op. cit.*, p. 63.

farmer comes when the «netto» (bean) is in flower (March-April) and helps his landlord to clear his grain farms [1].

TYPES OF MIGRATORY LABOUR

With respect to the age group of migrants, he is the youth who goes to work abroad. Mossi migrants for example are usually in the 16-30 age group [2]. The 1960 census in Ghana showed that the immigrant in Ghana is confined almostly to the economicly active group. Sixty five per cent of them lies in the 15-64 age group. The census showed also that the average age of the immigrant population is 24. This is a general phenomenon not only in west Africa, but also in all tropical Africa. It is due to the efforts which an immigrant has to make either on his journey, in his work, or even in dwelling in the host country in which he is with five or six in one room or even a verandah.

So the older a man is, the less he can endure such physical efforts. It is clear also that his obligations towards his family decrease as they grow up. At this stage of life he is a receiver of the doweries of his daughter, and of gifts from his young migrant relatives.

He is also a male migrant. Four fifths of all immigrants to Ghana made their original journey on their own. Of those who did not fifty eight per cent brought their wives, and half of these brought their children as well [3]. This phenomenon of leaving the wife in the home country is due to economic and social reasons. The economic reasons are re-represented in the relatively low wages paid for the labourer, which may not support a family. While leaving the wife at home means two incomes together ; the labourer's savings and the wife's income through cultivating the land. A wife, and the women as a whole, in these societies plays an effective role in the economic life of both the family and the village. This is because she is the person who does most of the agricultural work

(1) Jarrett, R. : The strange farmers of Gambia, *Geog. Rev.*, XXXIX, No. 4, October 1949, p. 649.
(2) Skinner, E. : Labour migration among the Mossi of the Upper Volta, p. 67.
(3) Caldwell, C.J.: *op. cit.*, p. 117.

particularly that concerning subsistence crops. So a migrant labourer in leaving his wife, besides increasing his income, does not cut the links between him and the village, to which he will return sooner or later (1).

Some of the migrants fear that he may loose his wife in the host country, as it happens with some of the Mossi migrants. Some Mossi migrants who live semi-permanently in Ghana establish liaisons with Ashanti women, but they do not marry them because of the Ashanti matrilineal descent principle. This would prevent them from taking children back to Mossi countries. So they are eager to obtain Mossi wives. In the same time a Mossi wife is able to «cultivate hard soils» when they return (2). Some of the minority accompany their wives, for fear of the liaisons with other men when she goes to visit her parents in his absence. They have a Mossi proverb «a woman goes to her father's house; a girl friend comes» (3).

TYPES OF EMPLOYMENT AND EMPLOYMENT CONTRACTS

We can discuss the jobs the migrant labourers attend in the host countries according to many factors i.e., the destination of the labourer, whether it is urban or rural, the degree of skill he has, the work he did in his country of origin.

As the largest number of migrants are unskilled, so most of them join work as unskilled labourers, either in urban or rural areas.

In rural areas they are farmers either in plantations as the Ibo in southern Cameroon, Fernando Po and some parts of the Ivory Coast, or on small farms as the case with cocoa farmers in Ghana. The Ibo dominates in the first two and the Mossi in the third. Here the jobs

(1) See a useful discussion of this point in ELKAN, W., Migrants and proletarians, East African Institute of Social Research, O.U.P., 1960; WINTER, E.H., Bwamba Economy, *op. cit.*

(2) SKINNER, E. : Labour migration and its relationship to socio-cultural change in Mossi country, *Africa,* 1960, 30, p. 389.

(3) *Ibid.,* p. 389.

coincide with their original trade in their native countries either in the Upper Volta, or in eastern Nigeria where agriculture employs over 75% of the working population. Until the discovery and exploitation of oil, agricultural commodities made up some 80% of the region's commercial assets. And so is the case of the settlement patterns where 87% of Eastern Nigerians continue to live in rural areas (1).

The Mossi were and still are, primarily an agricultural people, the products of the soil is the main national source of revenue. As they say «Land is the mother, its generation and its children; and provides the final resting place for all men» (2).

It seems that markets and trade have special attractions to those who are urban dwellers in origin, such as the Yoruba and Hausa of Nigeria.

As unskilled workers we find them joining internal trade. Internal trade in west Africa though largely in African hands, is not always strictly indigenous. Thus in the Ivory Coast all trading is in the hands of non Ivorians — mostly from Upper Volta, Mali, Niger, Nigeria and Guinea. Out of a sample of 20,000 petty traders in the Ivory Coast for instance, over two thirds were believed to be strangers of this kind; and one of the largest trades — the Kola trade — worth between £. 4-6 million a year is controlled by Dioula from Mali (3). The Yoruba prefer to choose trade in preference to any other act. The majority of Yoruba in Ghana, and nearly all those whose associations go back come from the heartland of the old Oyo Empire. Perhaps the incentive to migrate came from the deteriorating conditions they lived after the declining of their Empire.

Both the Yoruba and the Hausa are willing to begin trading in a very petty way, with a few boxes of matches, or lumps of sugar, in a way too petty to be worthy of the Ghanian. So it was the way they build the capital for further advance (4). The main water front store at Winneba was in

(1) BARRY, F., *op. cit.,* p. 169.

(2) SKINNER, E. : The Mossi of the Upper Volta, p. 107.

(3) HODDER, Growth and change in trade, in PROTHERO, M.R., *ed.,* A Geography of Africa 1969, Routledge, p. 444.

(4) STAPLETON, B. : West Africa, February, 1959.

the Yoruba hands, and Yoruba (Egbas) dominated the Fadama motor parts market on the outskirts of Accra before the new regulations of aliens, which Ghana began to put into action in 1969 [1]. The Kumasi market still keeps Yoruba festivals. In the same time the Hausa traders dominate the internal market in Kola and cattle trade. A part of this cattle trade is slaughtering cattle and marketing meat. Most of Kumasi's butchers were strangers, and particularly from Hausa origin, though now some Ghanians have replaced them after 1969.

The picture of monopolising internal trade by immigrants is well developed to the extent of the spread of social and economic phenomenon of the «landlord», and some of them specialise in receiving strangers of certain ethnic groups only [2].

The strangers dominance in the west African markets is repeated frequently. Barry indicates it also at Pendembu market in Sierra Leone [3].

The attraction of trade for the immigrant is due to many factors. Firstly trading as a job does not require special skill which may relatively be required in agriculture or industry. Secondly it needs less laborious work, i.e. than that required in mining. Thirdly it can start with a little capital, as we saw the Yoruba and Hausa began trading in a very petty way.

The Nigerian domination of diamond digging industry is a noteworthy feature. During the early forties, Yorubas who were the head labourers or clerks in the employment of the European diggers, having saved enough money, began to obtain digging licences and concessions from the chiefs. It has been said that 70% of current licences in Ghana are held by Nigerians. They are mainly Yorubas. Economists find in this type of migration the cause of the large marketing corporation in Nigeria, albeit, it has no diamond deposits on her soil.

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(1) Addo, M.O. : Immigration into Ghana, some social and economic implications of the alien compliance order of 18th November 1969, *Ghana Journal of Sociology,* vol. 6, No. 1, February 1970.

(2) Hill, P. : Landlords and brokers, A West African trading system, *Cahiers d'Etudes Africaines,* 23, vol. VI, 3, 1966, p. 350.

(3) Barry, I. : Traders in Pendembu, Sierra Leone, *Urban African Notes,* African Studies Centre, Chicago, December 1969, p. 59.

Another group displays special skill, and they do not represent themselves quantitatively but qualitatively such as the Dahomyens. Southern Dahomey made much benefit from the Lyon missionaries school established there to the extent that albeit Dahomay's poverty it had a large percentage of children of school age attending school than the Ivory Coast, Senegal, Sierra Leone or Gambia. In 1955 the percentages were 10, 8, 7, and 6 respectively [1]. As there were no jobs for them in their poor country, they became as an entrepot for exporting clerks and officers to other west African countries, especially the Francophone, like the Ivory Coast. This was clear from M. Houphouet Boigny's speech «Les Ivoiriens souffrent d'un complexe d'infériorité dû au fait que leurs frères de certains pays voisins ont bénéficié du temps de la colonisation d'une meilleure scolarisation et sont donc plus aptes qu'eux à occuper certains emplois» [2]. As they are not large in numbers relative to the native population, some call them the Jews of west Africa [3].

With respect to the type of employment contract, we have to bear in mind that, a written contract is something usual in town and mining areas, but it is not necessary in rural areas, though in plantation firms such as Firestone in Liberia, there are written contracts for two years [4]. In almost all of the cases the contracts are generally oral. But more formal arrangements are however gradually replacing customary services and with the development of the money economy, the tendency is more and more even between Africans of the same clan to make some sort of cash payment [5]. In such countries as Ghana, Gambia and the Ivory Coast where cash crop cultivation on a peasant basis prevails, a variety of forms of contract have developed.

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(1) Unesco : Statistical Year Book, 1969, p. 12.

(2) Revue Française de Science Politique : Les Dahoméens en Afrique de l'ouest, les conflits internationaux, vol. 17, 1967, p. 722.

(3) *Ibid.,* p. 722.

(4) Jurgens, W.H., Tracey, K., Mitchell, P.K.: *op. cit.,* p. 47.

(5) International labour office : First African Regional Conference 1960, Report of the Director General, p. 28.

These are the systems used on the cocoa farms in Ghana [1] :

1. The Abusa system which means tripartite division. An Abusa is a man who is employed by the farmer to look after one or more of his cocoa farms and his reward is a one third share of the cocoa he plucks. The Abusa system is not unique in Ghana, it certainly exists in the Ivory Coast, although it, nor any other share cropping system has been reported from the cocoa areas of Nigeria.

2. Nkotokuano man like the Abusa is concerned with looking after the farms, but his principal task is that of plucking cocoa. The sum per head paid to the labourer varies with cocoa prices.

3. The annual labourer : His primary purpose is to clear the land for establishing new farms, but he must be willing to undertake any task alloted to him. He is a wage employee completely maintained in food, clothes and lodging by his landlord.

4. Contract employment : This is a piece work employment for a fixed sum of money. Their usual work is weeding or clearing the land for new establishments.

5. Daily labourer who assists with any kind of work on the farm except plucking cocoa.

[1] Hill, P. : Social factors in cocoa farming, in Wills, B., *ed.* Agriculture and land use in Ghana, O.U.P., 1962, pp. 284, 285. See also I.L.O., African Labour Survey, Geneva, 1958, p. 68.

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CONTRIBUTIONS TO THE GEOMORPHOLOGICAL PATTERN AND STRUCTURAL FEATURES OF WADI EL-NATRUN AREA, WESTERN DESERT, EGYPT

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ABSTRACT

This work describes and interprets the geomorphological and structural features relevant to Wadi El-Natrun area. Through the analyses of the different landscapes in the area under study, the following three physiographic units are differentiated :

1. Gravel Plains ; 2. Table upland areas ; 3. Low land areas.

Detailed drainage map was constructed from aerial photographs and statistical studies were undertaken for the two main depressions in the area. The investigated data led to the recognition of high drainage density in Wadi El-Natrun compared with Wadi El-Farigh.

The main structural features reported in this area are Wadi El-Farigh anticline, Wadi El-Natrun graben and Dahr Tashasha horst-Gabal El-Hadid plateau. Two local unconformities were reported between the lower Pliocene, and the underlying lower Miocene and the overlying upper Pliocene. These are related to epeirogenic movements of post Miocene time.

Cylindrical structures build up an outstanding feature in the red pebbly sandstone of the lower Miocene clastics. These are attributed to ascending solutions rich in iron and silica that highly invaded the porous reaches of these sandy

facies and base of the lower Pliocene section. This hydrothermal activity is dated to the post lower Miocene-early lower Pliocene and did not disturb the sedimentary structures in the flushed sands. The geological history of the area investigated is also pointed out.

I. — INTRODUCTION.

This work deals with the geological features of Wadi El-Natrun area, Western Desert, Egypt. It is one of the prominent depressions in the Western Desert that could be observed from the Cairo-Alexandria desert highway at the Rest-house, half-way between Cairo and Alexandria. Wadi El-Farigh, another bordering topographic depression is noticed at kilometer 50 from Cairo. With the exception of Gabal Abou-Roash-Gabal El-Khashab area, near Giza pyramids plateau, the area between Cairo in the south and Wadi El-Natrun in the northwest is characterized by a low relief. The area under question is located between : Long. 30° 00′-30° 25′ East and Lat. 30° 15′-30° 30′ North. (See location map, Fig. 1).

The name Wadi El-Natrun was assigned to this depression by El-Maqurizi (an Arab traveller) in the 16th century. Many other names were given to this depression, such as Salt Field and Ein Horous (by Ancient Egyptians). The area of Wadi El-Natrun has received much attention since the third decade of this century. Some industries have been erected in the area depending largely on the occurrence of local resources such as Natron ($Na_2CO_3 . 10H_2O$), Salt (NaCl) and white sand. These natural deposits were applied for the production of caustic soda, soap and low grade glass. Early in 1954, groundwater development and land reclamation were undertaken for the purpose of maintaining a good living standard for the increasing population.

The area under consideration has been the scope of numerous geological studies since Russegger (1838) and particularly in the past twenty years. Several reports were submitted by different oil companies, hydrogeological investigations including pumping tests, water quality analyses and subsurface mapping were undertaken as well. Other eminent authors participated in studying the geologic set up of this district.

Among them we have Andrews (1902), Blanckenhorn (1901, 1921), Hume (1925), Sandford and Arkell (1939), Ball (1939), Bailey (1940), Merril and Owens (1947), Vischer (1947), Shata (1955), Shata et al.

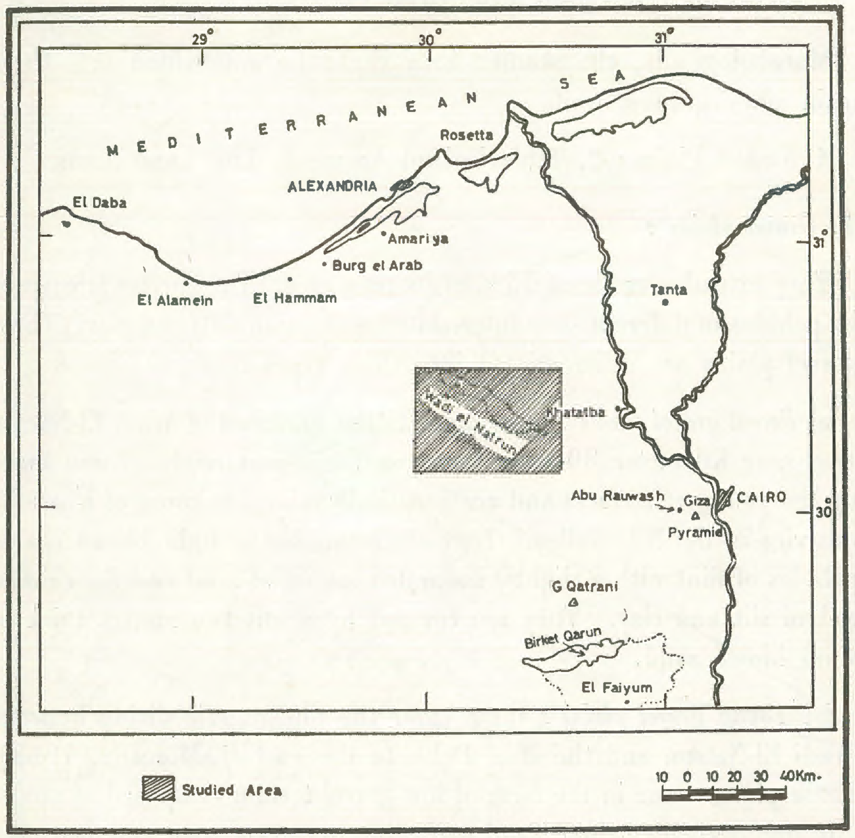


FIG. 1. — Location Map.

(1962), LaMoreaux (1962), El-Fayoumy (1964), Shata and El-Fayoumy (1967) and Abdalla (1970).

II. — GEOMORPHOLOGY.

The geomorphological approach in this work takes into consideration two fundamental elements, the topographic relief and the drainage pattern. (See morpho-tectonic map, Fig. 2). Data collected from

field measurements, aerial photograph analyses and topographic maps build up the framework of this study.

A. Topographic Relief.

Morphologically, the studied area could be subdivided into three main physiographic units :

1. Gravel Plains; 2. Table Upland Areas; 3. Low Land Areas.

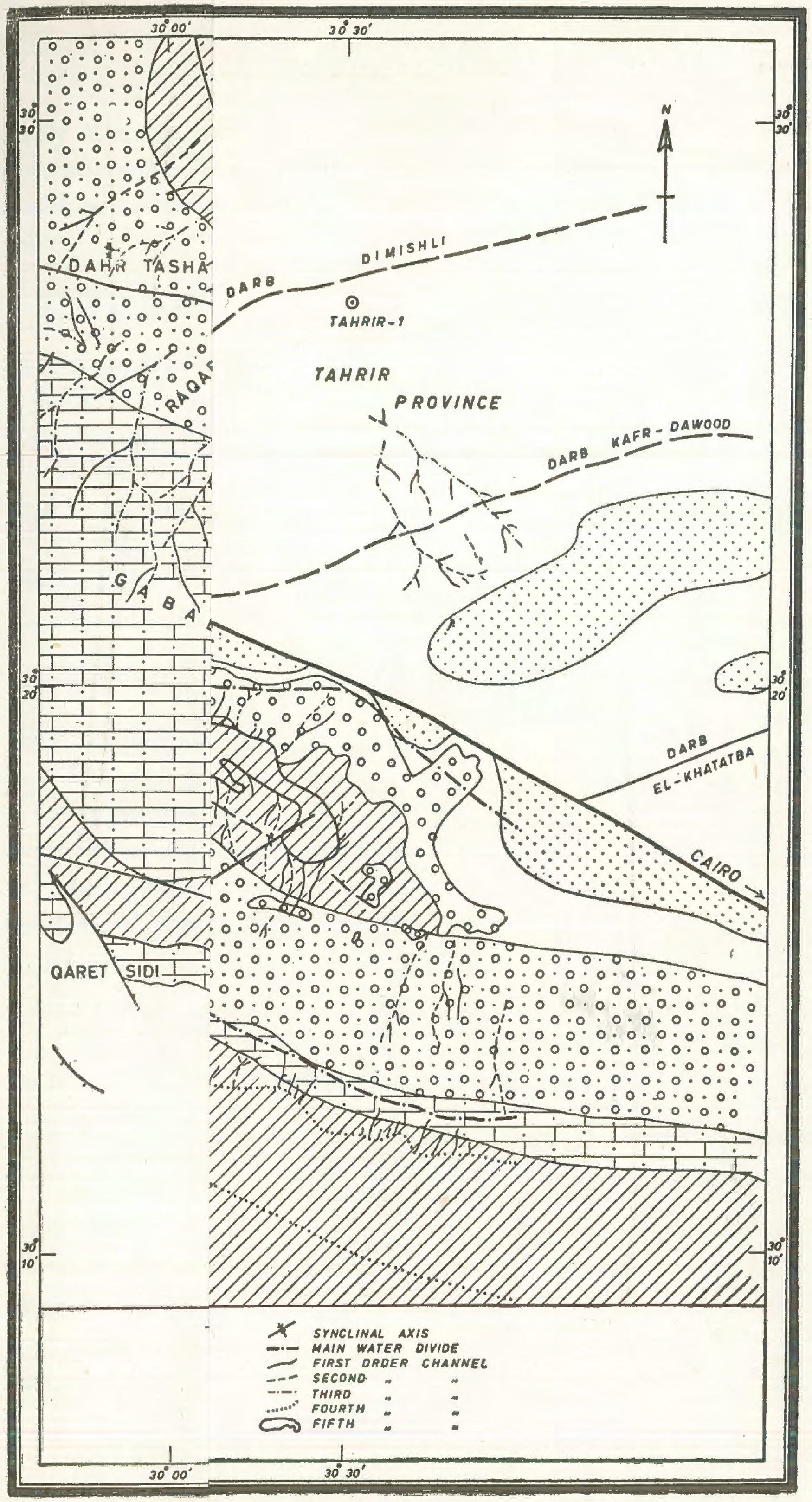
1. *Gravel plains :*

They extend over about 75% of its total area. The surface is covered by pebbles of different sizes intercalated with sand, silt, and clay. These gravel plains are differentiated into three types :

a) *Recent gravel plains :* these occur to the southeast of Wadi El-Natrun area near Kilometer 80 from Cairo on the desert road. These build up the youngest terraces and are genetically related to those of Khatatba quarries in the Nile Valley. They are composed of light brown coarse pebbles of flint with a slightly indurated matrix of sand and finer material of slit and clay. They are covered by about two meters thick of wind blown sand.

b) *Young gravel plains :* these cover the topographic divide between Wadi El-Natrun and the Nile Delta to the east (LaMoreaux, 1962). These plains occur in the form of low gravel terrain composed of moderate pebbles with drifted sand spreading over vast areas and rest over a dark marine clay bed. They are well developed in the east attaining a thickness of about 200 m. and less significant in the west of the studied area. Northwards, they grade into sands and are replaced by clays in Maryut area (Vischer, 1947).

c) *Old gravel plains :* these border Wadi El-Natrun and Wadi El-Farigh from the west and southwest and were defined by LaMoreaux (op. cit.). They cover great expanses without a defined morphological shape. They are mainly composed of glassy, dark brown, rounded, flint cobbles and boulders accompanied by smaller, well rounded pebbles,



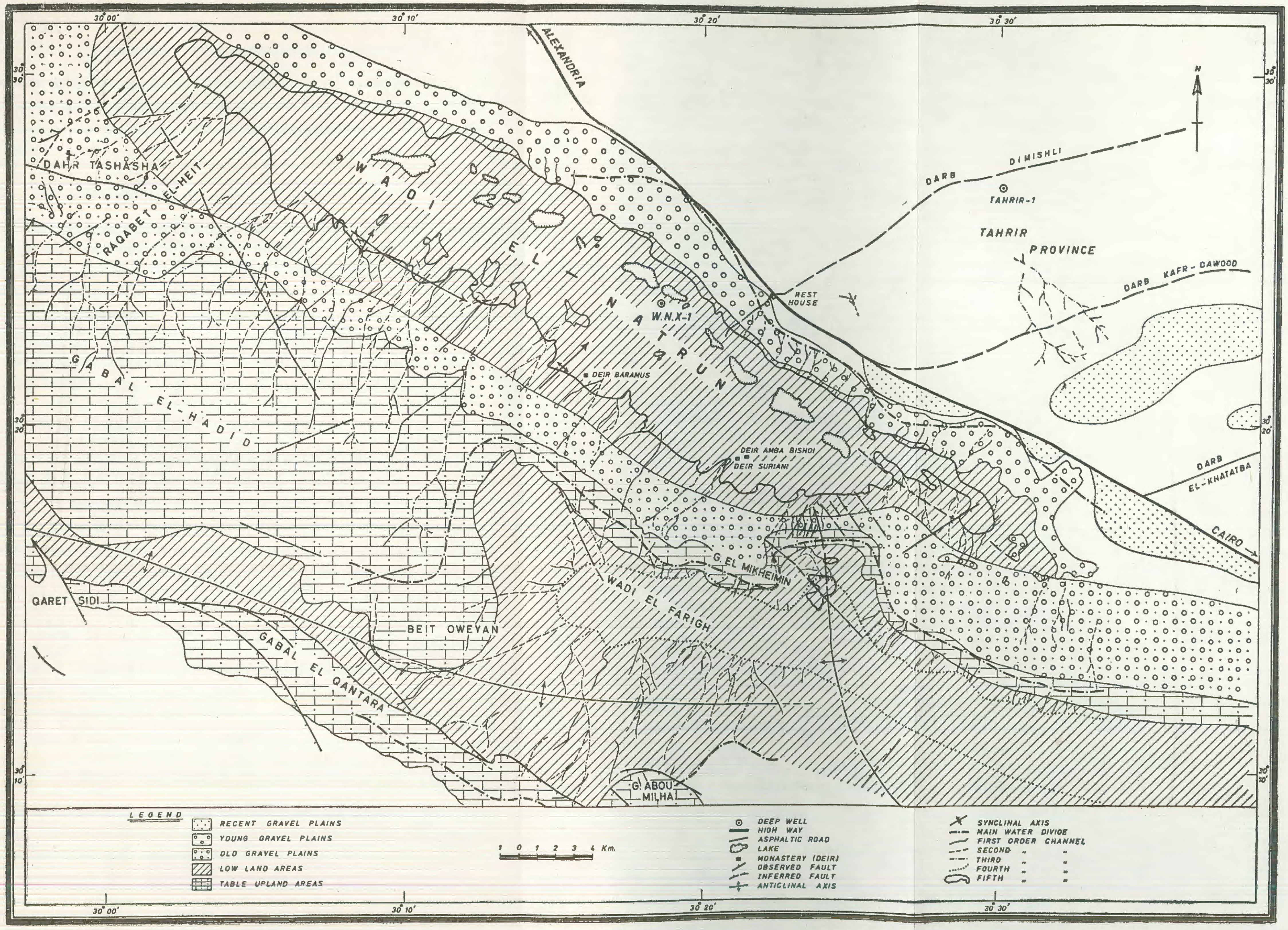


Fig. 2. — Morphotectonic Map of Wadi El-Natroun Area, Western Desert, Egypt.

mostly of milky quartz, together with silicified wood fragments and other occasional admixtures. These plains have been, most probably, formed by the primitive or Proto-Nile, the «Uhr Nil» of Blanckenhorn (1902).

2. *Table upland areas :*

These are formed of few scarps, of low topographic relief. They occur in the form of elongated ridges bordering the two main depressions : Wadi El-Natrun and Wadi El-Farigh. Some are capped by hard ferruginated sandstone as in Gabal El-Hadid or conglomeratic limestone as in Gabal El-Mikheimin. Others are capped by conglomeratic sandstone and chert gravels as in Beni-Salama and Kafr-Dawood.

The main topographic scarps in the present area are : Gabal El-Hadid, Gabal El-Mikheimin, Gabal Abou-Melha and Gabal El-Qantara.

a) *Gabal El-Hadid* (Δ 184 m.).

It is an elongated ridge extending in a NW-SE direction, bordering Wadi El-Farigh from the northwest and Wadi El-Natrun from southwest. It consists of a series of separate hillocks, one superimposed on the other in a step like manner. It is formed of loosely cemented sand, sandstone, pebbly sandstone and is usually covered by a thick cross-bedded, ferruginated sandstone bed. The iron cement gives it the reddish brown tint.

b) *Gabal El-Mikheimin* (Δ 95 m.).

It is an elongated ridge separating Wadi El-Natrun in the north from Wadi El-Farigh in the south. It is formed of sandstone with shale and clay intercalations and an occasional cover of conglomeratic limestone or ferruginated, cross-bedded sandstone.

c) *Gabal Abou-Melha — Gabal El-Qantara* (Δ 188 m. and 196 m.).

These lie to the south of Wadi El-Farigh and acquire the form of elongated ridges consisting of sandstones covered by nodular chert bands, conglomerates, and conglomeratic limestone.

3. *Low Land Areas :*

The main topographic low lands in this area are Wadi El-Natrun and Wadi El-Farigh depressions. The former is the most prominent and extends in a NW-SE direction for about 50 km., being 50 mts. below the surrounding table land. A series of salt lakes occupy the central low land of this depression with vegetation of the new reclaimed areas on both sides. The altitude of the lowest point in these lakes amounts to 24 mts. below sea level.

The latter is located some 15 km. to the south of Wadi El-Natrun. It is shallower with its lowest point lying about 4 mts. below sea level. It extends for about 70 km. nearly in an E-W direction with a width of about 7 km. Its bottom is covered by wind blown sands, pebbles, gravels, petrified wood and sand sheets. Wadi El-Farigh is separated from Wadi El-Natrun by Gabal El-Mikheimin, at the base of which crops out the oldest formation in the studied area. The western flank of Wadi El-Farigh slopes gently to the west, beyond which the old gravel plains extend to cover the eastern edge of the Western Desert.

B. Drainage Pattern.

The drainage system exhibits variations in shape, density, channel length and stream entrance. In the northern part of the studied area, north of El-Natrun depression, the slope gradient is very small, and the area is covered by loose clastics, accordingly, the drainage pattern is of the deranged to subparallel type. The density of the drainage system in this area is low. In the central and southern parts of the area, the drainage system is of the subparallel type, characteristic to fine clastics. The tributaries receive their water from the high ridges crossing the area nearly in an east-west direction, i.e. both Gabal El-Hadid and Gabal El-Mikheimin. The drainage pattern is shown on the morphotectonic map, Fig. 2.

Quantitative measurements for the drainage pattern of the two major wadis were carried out in an attempt to elucidate on statistical basis the statements concerning the position and texture of the investigated

area. Similar studies were undertaken by Said and Beheri (1961) in the area to the east of Cairo.

Horton (1945) introduced the controlling laws and techniques of drainage systems. Strahler (1952, 1954 and 1958) modified some of the parameters given by Horton. The present study is carried out following the modified techniques of Horton (1945) and Strahler (1958).

Wadi El-Natrun :

The northeastern slopes of this depression consist of sandy clay. The tributaries in this part are of very fine texture, low in density and of the deranged to subparallel type. The shape of the low order channels is dendritic, but when the fine drainage lines reach the scarp faces, where the slope gradient becomes greater, they change their pattern to be more or less parallel in shape, and join the main wadi by the shortest way. These are probably controlled tectonically and are thought to be affected by the joint system of the underlying sediments. Drainage pattern analyses were carried out for Wadi El-Natrun and Wadi El-Farigh and a drainage map was traced from the topographic map of the area (scale 1 : 100,000) with modifications from air photographs. Table (1) gives the quantitative drainage measurements, of Wadi El-Natrun.

TABLE (1)

Quantitative analysis of Wadi El-Natrun basin

1 Stream Order	2 No. of Streams	3 Bifurcation Ratio	4 No. of Streams Involved in Ratio	5 Products of Columns 3 and 4	6 Channel Length in Kilometers	7 Mean Length in Kilometers
1st	123				137.80	1.12
2nd	43	2.86	166	474.76	149.70	3.48
3rd	13	3.31	56	185.36	161.50	12.40
4th	1	13.00	14	182.00	18.50	18.50
5th	1	1.00	2	2.00	55.00	55.00
Total			238	844.12	522.50	

Due to stream irregularities, bifurcation ratios between successive channel orders differ within the same basin, if a general observance of a geometric series exists. To reach a representative bifurcation ratio, Strahler (1954) used a weighed mean bifurcation ratio calculated by multiplying the bifurcation ratio of each successive pair of orders by the total number of streams involved in the ratio (column 5) and taking the mean of the sum of these values by dividing the products by the number of streams involved in the ratio (column 4). The drainage density can be computed by dividing the total channel lengths in kilometers on the surface area of the basin in square kilometers.

Thus the weighed mean bifurcation ratio of Wadi

$$\text{El-Natrun} = \frac{\text{Sum of Column 5}}{\text{Sum of Column 4}} = \frac{844.12}{238.00} = 3.55$$

$$\text{Drainage density D d} = \frac{\text{Total lengths (Column 6)}}{\text{Surface Area}}$$

$$= \frac{522.50}{505} = 1.03$$

The stream frequency and mean stream lengths are plotted against stream order on semi-logarithmic paper (Fig. 3). The part of the frequency curve for the *1st, 2nd* and *3rd* orders fits with the geometric progression proposed by Horton (1945), and is nearly linear in shape. The other part of the curve representing the high order streams (*4th* and *5th*) shows an abrupt change, suggesting that geometric progression is not observed in the lower part of the curve. This is due to the complicated geomorphological development of the *4th* and *5th* order basins. The mean stream length curve shows a geometric progression for the *1st, 2nd* and *3rd* order streams which is lower than that of humid regions. Due to the composite history of the *4th* and *5th* order streams, their average lengths are higher than expected and exhibit no geometric progression.

Wadi El-Farigh :

Its tributaries drain mainly Gabal El-Mikheimin to the north, Gabal Abou-Melha — Gabal El-Qantara to the south and Munqar El-Reswa to

the west. It traverses the Cairo-Alexandria highway near Gabal Hamza to reach the Nile Delta and the Rosetta branch of the Nile near Wirdan Village. The channels of the northern tributaries are fine and short while those of the southern part are longer, deeper and of subparallel shape (Fig. 2). Table (2) gives the quantitative drainage measurement of Wadi El-Farig basin.

TABLE (2)

Quantitative analysis for Wadi El-Farigh Basin

1 Stream Order	2 No. of Streams	3 Bifurcation Ratio	4 No. of Streams Involved in Ratio	5 Products of Columns 3 and 4	6 Channel Lengths in Kilometers	7 Mean Length in Kilometers
1st	74				66.90	0.90
2nd	14	5.29	88.00	465.52	53.50	3.82
3rd	3	4.67	17.00	72.39	21.40	7.13
4th	1	3.00	4.00	12.00	72.00	72.00
Total			109.00	549.91	213.80	

$$\text{Mean Weighed Bifurcation Ratio} = \frac{549.91}{109.00} = 5.05$$

$$\text{Drainage density D d} = \frac{213.80}{303.00} = 0.70$$

The frequency of streams as well as mean stream lengths are plotted against the channel order (Fig. 3). It shows a direct geometric progression for the *1st, 2nd* and *3rd* orders, while the part of the curve which represents the fourth order channels changes abruptly due to a composite morphologic history of the high order basins. Thus, the drainage density of Wadi El-Farigh is lesser than that of Wadi El-Natrun, being of the magnitude 0.70 and 1.03 respectively.

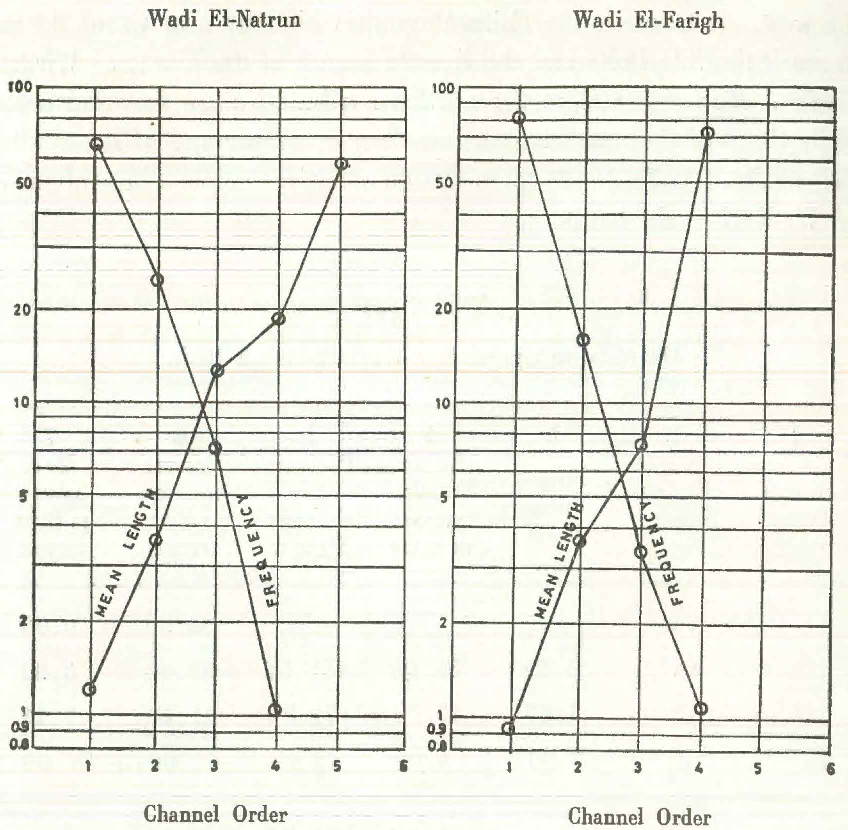


FIG. 3. — Graphical representation for stream frequency and mean stream lenght against channel order.

III. — STRUCTURES.

A. REGIONAL.

The regional structural element of the northern belt of the Western Desert is the Marmarican homocline. In the studied area, strata dip gently northwards on the eastern part of this homocline. With the exception of Abou-Roash and Gabal Qatrani areas, the north Western Desert plateau is not structurally affected by superficial major tectonic elements. Generally, the district is of low relief, and most of it, is covered by wind blown sands and gravels, accordingly it is rather difficult to

recognize the structural elements directly in the field. The structural configuration of the northern Western Desert was the subject of many investigations by regional geologists and geophysists.

B. LOCAL.

The structural pattern of the area under investigation is revealed through field work, aerial photographs, and the whole picture is compiled through the coordination and interpretation of geophysical data. The morpho-tectonic map (Fig. 2) shows the main structural elements present in Wadi El-Natrun district. Primary structures belonging to the bedding and non-bedding types are common. The following is a brief description for these structures :

1. *Bedding structures*

Bedding is a common feature characteristic to all sediments and sedimentary rocks exposed at Wadi El-Natrun district. Cross-bedding and graded bedding are diagnostic to sandstone beds.

a) *Cross-bedding*

It is well developed in the coarser sandstone of the red pebbly sandstone (Pl. I, A) and partially in the clayey sand of the lower Miocene. This structure is shown clearly in Gabal El-Hadid and Gabal El-Mikheimin localities. It consists of sets of variable thickness, ranging from 0.05 mts. to 0.50 mts. that are nearly parallel and dip with an average angle of about 18°. Most probably, it is of fluviatile origin since the surfaces are parallel and dip with a small angle in one direction.

b) *Graded bedding*

It is well exhibited in the clayey sand as well as in the ferruginated sandstone and the red pebbly horizon of the lower Miocene section. The thickness of graded beds, generally, bears a direct relation to the coarseness of the sediment. The graded beds in the red pebbly horizon (coarse sand) are relatively thick, while those in the clayey sand are thin.

2. *Non-bedding structures.*

The main non-bedding structure represented in Wadi El-Natrun deposits is the cylindrical structure. This structure is well developed in the red pebbly sandstone (Pl. I, B). It is produced by the action of ascending hydrothermal solutions rich in iron and silica that highly invaded the fairly porous reaches of the lower Miocene and base Pliocene. Vischer (1947), stated that ferrugination occurred contemporaneous with deposition, i.e. Syngenetic. Petrographic studies of these tubes, however, revealed that ferrugination took place after deposition followed by silicification, i.e. Epigenetic. (Philip and Abou-Khadrah 1973). The detrital quartz grains are rimmed with iron oxide followed outwards by silica overgrowth having a bipyramidal crystal form. (Pl. II, A). This hydrothermal activity is dated to the post lower Miocene-early lower Pliocene time. Ferruginated and silicified sand tubes preserve their primary structures (graded and cross bedding). These tubes are indurated and dark in colour externally in contra-distinction to the friable, loose nature and light colour internally. These phenomena are very similar and could be equated with the cylindrical structures and colouration of Gabal Ahmar to the east of Cairo described by Shukri (1953).

3. *Secondary structures.*

The main structural elements displayed in Wadi El-Natrun area are faulting and unconformities. Folding is not a dominant feature. With the exception of Wadi El-Farigh anticline, folds recorded in the present area are small flexures and undulations related to neighbouring faults.

a) *Folds.*

The most pronounced folding phenomena in Wadi El-Natrun region is the gentle fold of Wadi El-Farigh in the southeast corner of the mapped area (Fig. 2). It is a gentle plunging anticline swinging WNW-ENE and extends for about 70 kms. Sandford and Arkell (1939) mentioned that El-Farigh depression is excavated in Oligocene sediments. Lower

Miocene clastics are reported occupying the core of this fold and Pliocene sediments build up its flanks. The origin of Wadi El-Farigh anticline, from the authors point of view, is believed to be due to tilting action from bordering faults and not due to compressional forces. This is justified by the fact that its amplitude is very small, much less than folds relevant to the Syrian Arch system formed by compressional forces.

b) *Faults.*

Three sets of fault trends are reported in northern Egypt in general and in the investigated area in particular. These are the Clysmic, trending NW-SE, the Mediterranean, running E-W and the Aqaba, trending NE-SW. Most of the fault planes are difficult to trace in the studied area. Some of them, however, are delineated through the high intensity of ferrugination and silicification, while others are detected from stratigraphic relationships and through geophysical analyses. Faulting in general is dated to two episodes, i.e. pre-early Oligocene and post late Miocene. Some of these faults were rejuvenated during the upper Neogene and along the same planes reflecting themselves on the surface. Bayoumi and Sabri (1972) interpreted a NE-SW magnetic anomaly in Wadi El-Natrun - Qatrani area and stated that it is an indication of a deep seated fault with the same trend affecting the area down to the basement complex.

Wadi El-Natrun depression is delimited by a northern fault, separating the upthrown block to the northwest from the main bulk to the southeast where the broad magnetic low exists. These pre-Miocene uplifts are tentatively of Oligocene time. This signifies that Wadi El-Natrun graben initiated in late Oligocene, being contemporaneous with the Gulf of Suez. Most of the major faults follow a NW-SE and E-W directions. The latter exists only in the southern part delineating Gabal El-Qantara and Gabal Abou-Melha from the north. Some swing to become NW-SE and form what is known as crescentic faults. Two major structures, attributed to Clysmic faulting, are reported in Wadi El-Natrun area. These are Wadi El-Natrun graben and Dahr Tashasha horst.

(1) *Wadi El-Natrun Graben.* This structure is detected in the subsurface, being parallel to the main direction of the depression. To the north, this graben is bordered by the Tahrir upthrown block, where as in the south, it is delineated by the down faulted northern flank of Wadi El-Farigh anticline. The northern fault is detected from drilling data and geophysical surveys. Parts of the southern fault are observed in the field and the rest is inferred. Also the Clysmic faults near Deir Makaryus are traced as delineating elements for the southern border of Wadi El-Natrun graben (Fig. 2).

The study of this structural picture would give the impression that Wadi El-Natrun proper was shaped by tectonic elements alone. However, it is more likely that it was formed by faulting and later modified by weathering processes. Graben forming faults initiated in pre-Miocene time (Oligocene), were rejuvenated along the same planes in younger ages (Middle Miocene and Lower Pliocene). Weathering and chemical transportation processes affected the floor of the structure especially in late Pliocene and were continuously active during the Pleistocene. These processes resulted in the present configuration of this topographic depression.

(2) *Dahr Tashasha Horst — Gabal El-Hadid Structures.* These structures lie to the northwest of Wadi El-Natrun depression. They acquire the form of an upthrown block between two faults running nearly in NW-SE and E-W directions. The NW-SE fault borders Dahr Tashasha from the northeast and continues to the southeast to bound Gabal El-Hadid plateau from the northeast. Also Gabal El-Hadid occurs in the form of a structural plateau, as a part of the northern flank of El-Farigh anticline, titled northwards as a result of faulting. Ferrugination and silicification are intense in this particular locality as a result of faulting, which created accessible ways for the iron and silica rich, invading hot solutions. The throw of these faults amounts to + 50 mts.

C. Unconformities.

Epeirogenic movements of slow rate and of regional character are the main cause for transgression and retreat that occurred in the area and

gave rise to erosional truncation of stratigraphic units. The reported unconformity surfaces are described from base to top as :

1. *Lower Miocene-Lower Pliocene Unconformity :*

This erosional surface is well exhibited in Gabal El-Mikheimin where the conglomeratic sandy limestone overlies the cross-bedded lower Miocene sandstone unconformably. These strata were tilted in late Miocene followed by erosional truncation before the deposition of the lower Pliocene carbonates which dip by an angle of about 2° to the north-northeast (Pl. II, B).

2. *Lower Pliocene-Upper Pliocene Unconformity :*

Upper Pliocene strata overlap the lower Pliocene in the northern sector of Wadi El-Natrun area. The older formation dips by an angle of about 2° to the NNE while the younger formation and Plio-Pleistocene limestones acquire a dip of about 1° in the same direction. The tilting of these strata may be attributed to rejuvenation of faulting in late Pliocene-Pleistocene times.

IV. GEOLOGICAL HISTORY.

The rocks exposed in Wadi El-Natrun district are of sedimentary origin and range in age from lower Miocene to recent. They manifest a variety of environments, being fluvio-marine, lacustrine and continental. This facies change is related to the old drainage system that once debouched in Wadi El-Natrun area during the Oligocene and early Miocene times, Shata et al. (1962). By the close of the Miocene and the outset of the Pliocene, a general rise of the continent is recorded and the old tributaries of the Proto-Nile ceased to discharge their sediment load from the Red Sea mountains. Since then, the recent Nile came into existence and started to excavate its present course and different gravel terraces were deposited. The land rise initiated excavation and weathering associated with chemical transportation processes created this topographic depression on the desert plateau.

V. SUMMARY AND CONCLUSIONS.

This work describes the geomorphological pattern and equally examines the structural features of Wadi El-Natrun area. Geomorphologically, the topographic relief and drainage pattern are the fundamental criteria analysed. The studied area is subdivided into three main physiographic units; Gravel plains, Table upland areas and the Low land areas. The gravel plains cover more than 75% of the investigated area. They are differentiated into three distinct types; recent gravel plains, young gravel plains and old gravel plains.

The table upland areas acquire the form of low topographic scarps with hard silicified and ferruginated beds. The main topographic scarps are : Gabal El-Hadid, Gabal El-Mikheimin, Gabal Abou-Melha and Gabal El-Qantara. The topographic lows are Wadi El-Natrun and Wadi El-Farigh depressions. The drainage pattern of the whole studied area is analysed and its results are quantitatively tabulated. It is revealed that Wadi El-Natrun is a wide wadi of the fifth order, while Wadi El-Farigh is of the fourth order. The drainage density of the former is higher than that of the latter, being 1.03 and 0.70 respectively.

Structurally, the area of Wadi El-Natrun displays primary structures belonging to the bedding and non-bedding types. Cross bedding, graded bedding and non-bedding structures are observed and interpreted. Faulting and unconformities play an important role in the structural configuration of Wadi El-Natrun area. Folding, on the other hand, is not a prominent feature except for Wadi El-Farigh anticline. Clysmic faults as well as Aqaba trend are detected in the subsurface. The initiation of Wadi El-Natrun structure is deemed to these faults in late Oligocene time, being contemporaneous with the Gulf of Suez. Wadi El-Natrun graben and Dahr Tashasha horst are the major features formed by these clysmic faults.

The Pliocene boundaries are delineated by unconformity surfaces with both the underlying lower Miocene and overlying upper Pliocene formations and Plio-Pleistocene sandy limestones.

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B. — Cylindrical structures at Gabal El-Hadid.

A. — Ferruginated sandstone with Quartz grains rimmed by iron oxide followed outwards by silica overgrowth. X : 45.

B. — Unconformity surface between the Lower Miocene cross-bedded sandstone and the overlying Lower Pliocene conglomeratic limestone.

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